DOCUMENT RESUME

ED 022 336 EF 001 720

ACOUSTICS AND EDUCATIONAL FACILITIES. A GUIDE FOR PLANNERS AND ADMINISTRATORS.

Rensselaer Polytechnic Inst., Troy, N.Y. Center for Architectural Research.

Spons Agency-New York State Education Dept., Albany. Div. of Educational Facilities Planning.

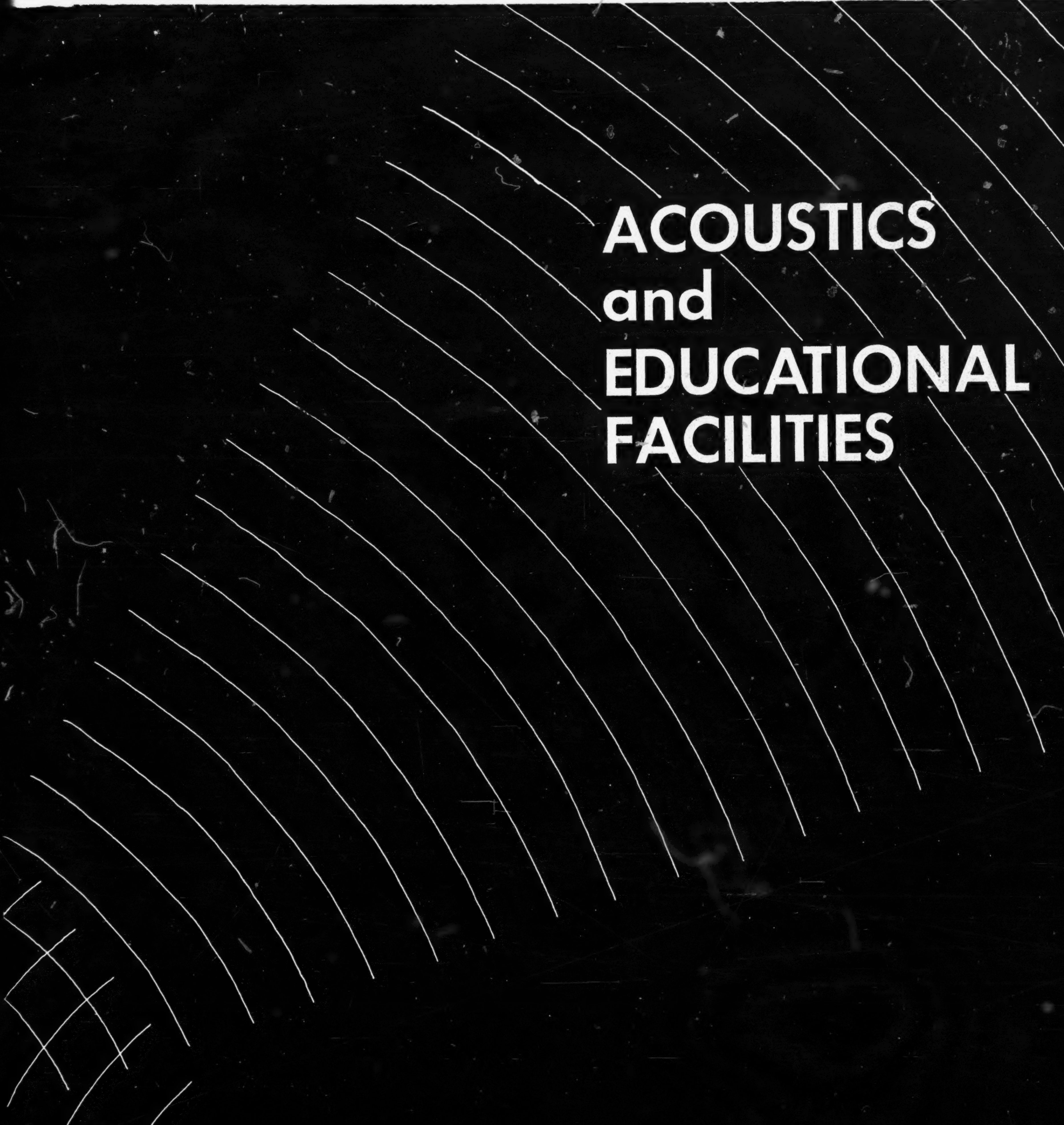
Pub Date Dec 66

Note-129p.

EDRS Price MF-$0.75 HC-$5.24

Descriptors-ACOUSTICAL ENVIRONMENT, *ACOUSTICS, CONTROLLED ENVIRONMENT, *EDUCATIONAL FACILITIES, ENVIRONMENTAL CRITERIA, ENVIRONMENTAL INFLUENCES, *SCHOOL PLANNING

An attempt to gather and organize information regarding acoustics in schools, and a planning guide for school architects and administrators, this report can be useful at various stages in school design, particularly analysis, planning and construction. To accomplish these goals two attitudes are necessary -- (1) acoustics must be thought of as more than "removal of noise," and (2) the concept of acoustics as an "after the fact" curative for sound problems should be replaced by inclusion of acoustical considerations at every level of architectural design. Guidelines are oriented to provide the designer with--(1) an understanding of basic acoustical principles, (2) the ability to perform basic analytic measurements, and (3) an insight to identify acoustical problems which demand a greater degree of technical skill. Chapters include--(1) basic principles, (2) acoustics and architectural programing, (3) acoustics in school planning, (4) acoustics and facilities design, and (5) acoustics and noise control. The information is thoroughly illustrated, supported by a bibliography, and followed by a checklist for planners and administrators. (RH)



ACOUSTICS and EDUCATIONAL FACILITIES

• A GUIDE FOR PLANNERS AND ADMINISTRATORS

EF001720

"PERMISSION TO REPRODUCE THIS
COPYRIGHTED MATERIAL HAS BEEN GRANTED
BY W. B. Haessig Director
Div. Educ. Facilities Planning
TO ERIC AND ORGANIZATIONS OPERATING
UNDER AGREEMENTS WITH THE U.S. OFFICE OF
EDUCATION. FURTHER REPRODUCTION OUTSIDE
THE ERIC SYSTEM REQUIRES PERMISSION OF
THE COPYRIGHT OWNER."

Copyright, Division of Educational Facilities Planning, New York
State Education Department, 1966
Library of Congress Catalogue Card Number: 67-18811

ACOUSTICS and EDUCATIONAL FACILITIES

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
OFFICE OF EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL OFFICE OF EDUCATION POSITION OR POLICY.

A GUIDE FOR PLANNERS AND ADMINISTRATORS

A report prepared by the Research Staff, Center for Architectural Research, Rensselaer Polytechnic Institute, Troy, New York, and sponsored by the Division of Educational Facilities Planning, State Education Department, The University of the State of New York. . . . . . . December 1966

ED022336

CONTENTS

Preface
The Concern
The Approach

1 Basic Principles

- the nature of sound 3
- the measurement of sound 5
- other characteristics of sound 10

2 Acoustics and Architectural Programming

- programming - the definition of building requirements 15
- programming considerations for sound quality, speech and noise control 18
- reverberation and programming considerations 27
- summary 30

3 Acoustics and School Planning

- acoustics and the planning process 35
- acoustics and site 39
- acoustics and plan types 42

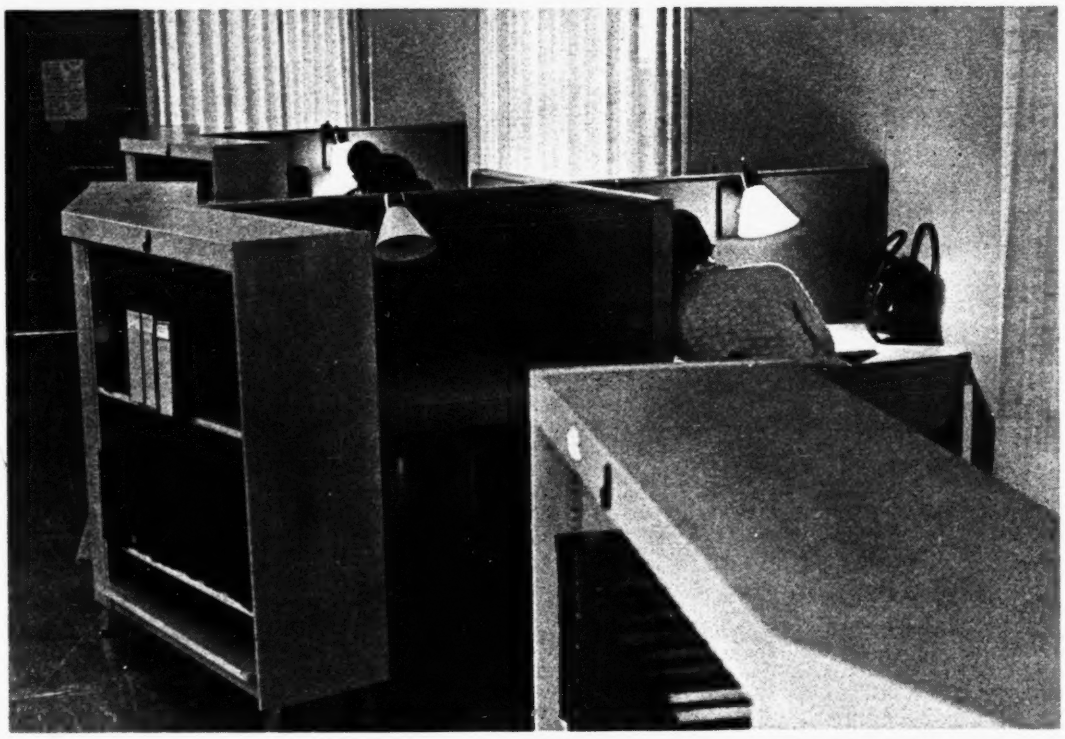
4 Acoustics and Facilities Design

- acoustics within educational spaces 55
- design of large group spaces 58
- design of spaces for music 67
- design of other educational facilities 71
- flexibility and open planning 73
- sound systems 79

5 Acoustics and Noise Control

- building elements and sound transmission 83
- mechanical equipment and noise transmission 90

Credits and Sources 99
Index 101
Bibliography 103
A Checklist for Planners and Administrators 113



PREFACE

This report does not present new research in the field of acoustics, nor does it propose a specific solution or "cure-all" for acoustics in school planning.

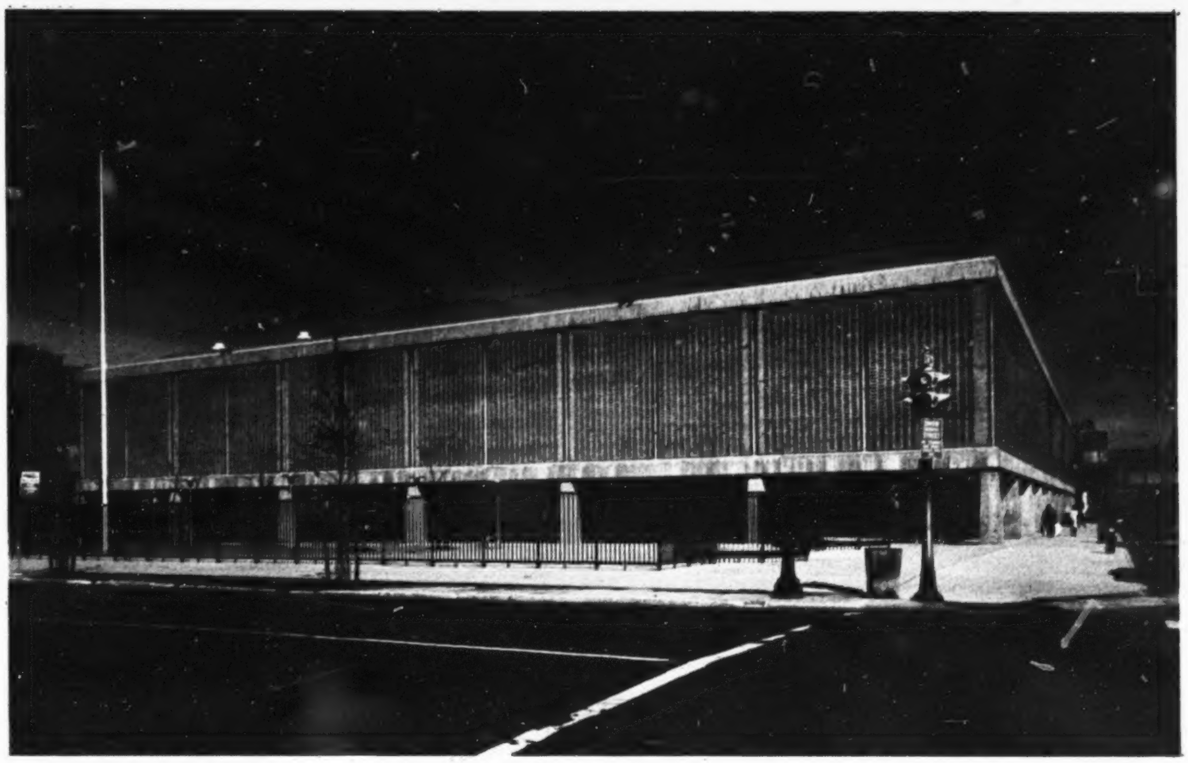
Rather it is an attempt to gather and organize information regarding acoustics in schools, as planning guidance for planner and administrator . Hopefully the report will be useful at various stages in school planning by virtue of what it says and how well it says it. If it communicates a few basic principles for good acoustics, and if those who shape our educational facilities respond appropriately, schools which provide better acoustical environments for learning should be achieved.

THE CONCERN

Planning and building a school is a complex operation. Many people and groups of people participate in the intricate process of determining the need, developing a program, planning the structure, supervising the construction and paying for the finished product. At all stages many considerations compete for the attention of owner and architect. This publication, devoted to the consideration of acoustics in school planning, does not demand that this particular consideration be favored above all others; it simply asks that acoustics be given appropriate consideration at each stage together with other design considerations.

To accomplish this goal, two attitudes are necessary:

First, acoustics must be thought of as more than "removal of noise". There must be a recognition that wanted and unwanted sounds are involved, the former to be protected and reinforced and the latter to be supressed or diverted.



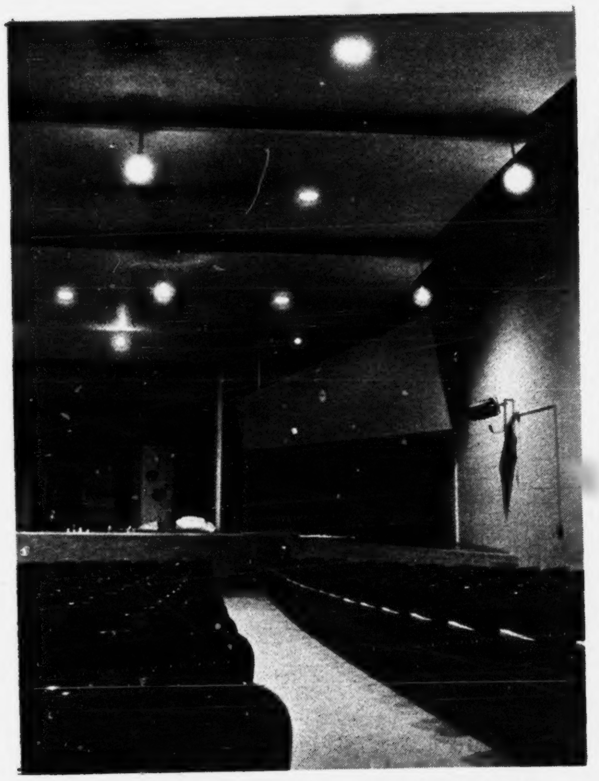
acoustics as a site consideration

Second, the concept of acoustics as an "after-the-fact" curative for sound problems should be replaced by inclusion of acoustical considerations at every level of architectural design.

A consideration of acoustics throughout the design procedure should be integrated with other aspects of the architectural process. However, as with structural design, lighting and mechanical equipment, the architect cannot be expected to display technical expertise in all phases of acoustical design. He should be sufficiently knowledgeable to be able to:

- understand basic principles
- perform basic analytic measurements
- identify problems which demand greater technical skill

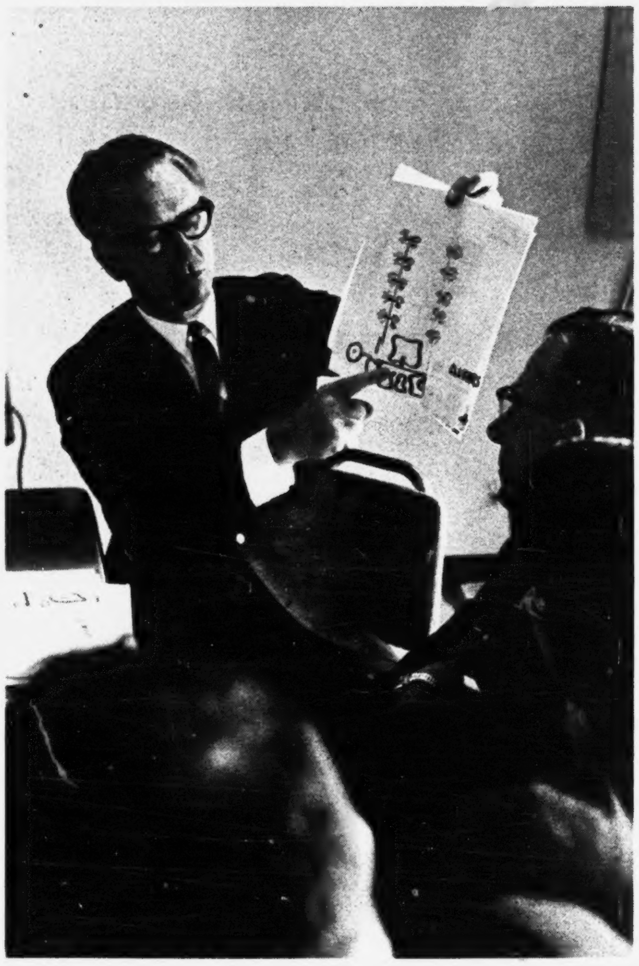
Architects and administrators need not achieve the same level of acoustical competency. The architect's skill should include a design and analysis capability, while the administrator's familiarity with the subject will be more limited. In any case, both should be sufficiently familiar with basic principles so that together they can intelligently evaluate proposed designs or problem correctives, and can articulately exchange ideas in a discussion of acoustics.


acoustics within facilities

acoustics as a technical concern

In the area of analysis, it is obviously important for the architect to be able to measure and evaluate proposed designs in terms of their acoustical performance. He should also be able to do the same with existing facilities. Of equal importance, he should be well aware of the point at which the complexity of the proposed design or existing situation calls for the help of professional acoustical consultants.

The identification of problems which demand higher levels of technical skill is an important one. Acoustical consultants will agree there are many straight-forward design situations that can be accomplished with standard procedures; there are, however, cases in planning schools which demand sophisticated analysis and the benefit of great knowledge. Architects should understand the special demands of such acoustical problems, and the need to employ and compensate expert advice.



THE APPROACH

In order to accomplish the dual task of, first, considering acoustics for schools at several levels of complexity and, second, relating this to appropriate people and competencies, the material that follows has a specific organization.

Part 1, "Basic Principles", provides a brief review of acoustical terminology and principles. This part should be of general interest to administrators and thoroughly understood by architects.

Part 2 and Part 3, "Acoustics and Architectural Programming" and "Acoustics and School Planning" relate acoustics to development of the building program and subsequent steps in planning. These sections are intended to reinforce the concept that acoustical planning is a continuous process including site selection and building programming, as well as building planning and facilities design. Here the school administrator and architect work together and both have a major responsibility to be well-informed.

Part 4 and Part 5, "Acoustics and Facilities Design" and "Acoustics and Noise Control", are directed primarily to the architect in order to give him some specific help in designing facilities, correcting problems, and dealing with other matters of a specific nature.

Because a guide covering all available knowledge of all aspects of acoustics for schools would be far too voluminous and complex for the uses mentioned above, numerous references are provided at the end. For any topic which is covered rather generally, the reader can pursue the related references for an "in-depth" study.

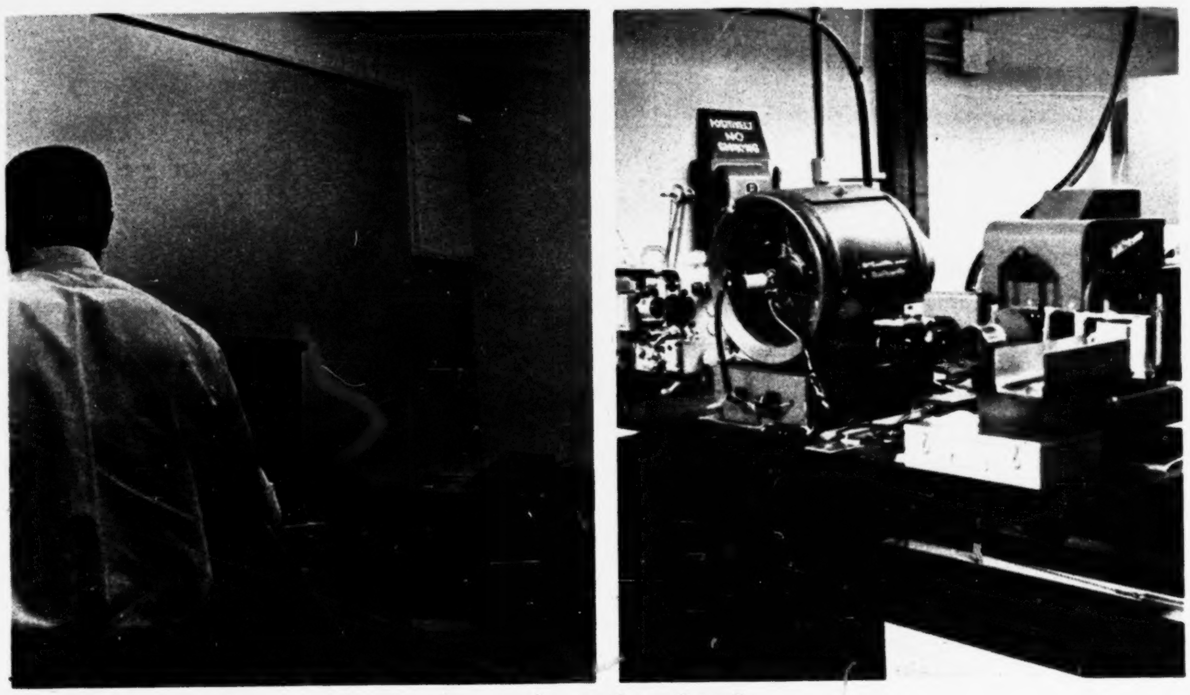
1

BASIC PRINCIPLES

- THE NATURE OF SOUND
- THE MEASUREMENT OF SOUND
- OTHER CHARACTERISTICS OF SOUND

• THE NATURE OF SOUND

The key to an understanding of acoustics and acoustical control lies in a firm grasp of the fact that sound is a form of energy and that acoustical design is the manipulation of this energy. Energy is required to produce a sound wave: the energy in a teacher's voice sets the air in the classroom in vibration and the electrical energy in a magnetic coil causes the diaphragm of an auditorium loudspeaker to vibrate, in turn energizing the air.



sound sources - man-made and mechanical

Thus rapid fluctuations are created in the air, and, because of the elasticity and mass of the body of air, a succession of waves travels outward from the sound source. A listener in the path of this wave train will gather a portion of the energy through the trumpet-like formation of the outer ear. This energy then causes a vibration of the ear drum, a transmission through the mechanisms of the inner ear, and finally, a pattern of nerve impulses which register in the brain as sound.

wanted sound

unwanted sound

Any vibration can act as a source for a sound wave. Deliberate generation of sound occurs in the voice or loud-speaker diaphragm previously mentioned - or in the vibrating string of the violin, the vibrating air columns of a trumpet or an organ pipe, the movement of a drum head, and other similar devices. Sound waves are also an unwanted by-product of a rotating fan, a refrigerator motor, a riveting gun, a gasoline engine, the impact sounds of a hammer, or the knobs on snow tires. In all cases, there is a quick and usually periodic distortion of the adjacent and elastic air and the setting up of a radiating series of waves which produce the sensation of sound.

For purposes of discussion one can, therefore, talk about unwanted and wanted sound. In the first case, the term noise is used in the sense of unwanted sound; in the second, the problem is that of distributing sound intended to be heard in such a way that it is clearly audible and of good quality. In the first, the problem is that of suppressing sound energy at its source or providing a barrier to transmission somewhere along its path. In the second, the problem is one of conserving available sound energy and distributing it without undesirable distortion and at an adequate energy level. Later discussions of facilities design elaborate on these points.

• THE MEASUREMENT OF SOUND

Two basic characteristics of sound are frequency and the flow of sound energy, or sound power.

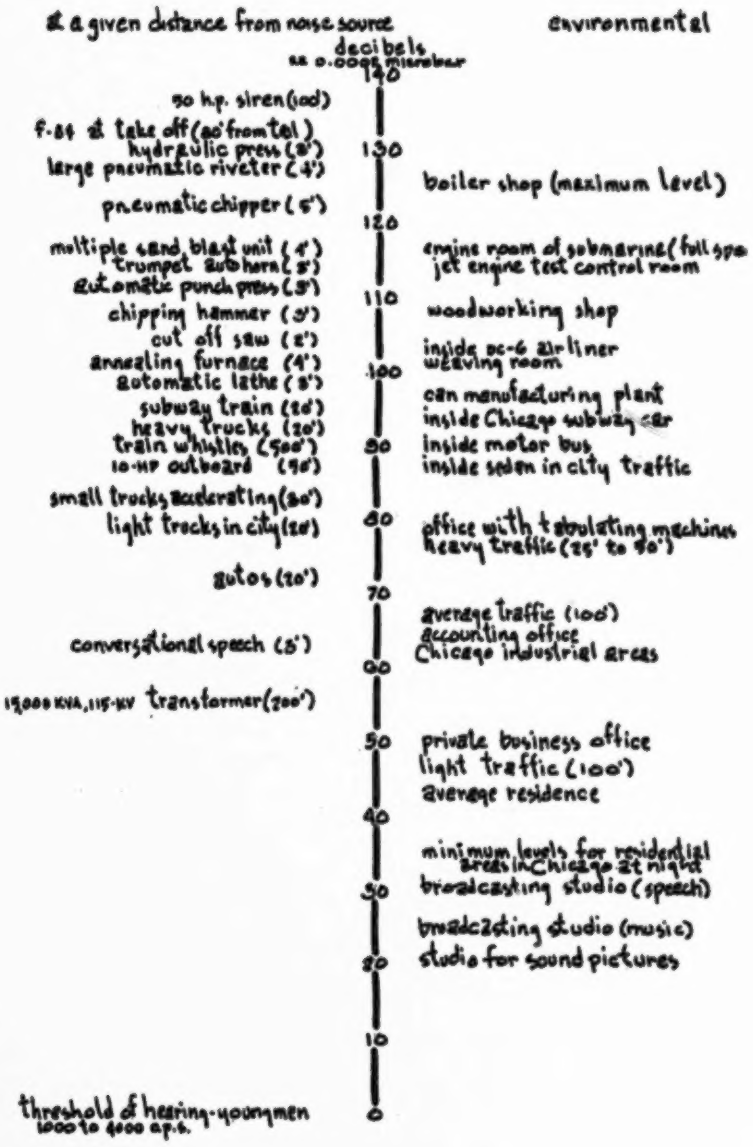
The flow of sound energy is not unlike the flow of light or the flow of electrical energy through the cross-section of a wire. It can be measured in the electrical power unit of the watt by defining a cross-section through which the sound energy flows; this gives the sound power unit or intensity, in terms of watts per square centimeter.

The vibratory or wave nature of sound sources and sound transmission is measured in terms of frequency - the number of complete cycles occurring per second. The subjective reaction to frequency is pitch. Middle "C" on the piano has a frequency of 256 cycles per second (cps): the "A" reference tone for musical groups has a frequency of 440 cps. Upper and lower limits of audible sound are 20 cps and 20,000 cps. Current literature commonly uses "Hz" to designate "cycles per second" but this document will continue to use the more easily remembered "cps".

The pressure variations in the material conducting the sound have a direct relationship to the wave energy; measurements are often given in terms of effective pressure (mathematically the root mean square value - rms) in dynes per square centimeter (microbar). The intensity in watts per square centimeter varies as the square of the rms pressure.

As with the other senses, the ear responds in a somewhat complicated fashion to auditory stimuli. In lighting, for instance, a given increase in level may be important at low intensities, but unnoticed at high intensities. Similarly, the significance of a change in sound intensity depends on the level at which it occurs.

As a partial adjustment for this, sound level is normally designated on a logarithmic scale, the decibel (db). In these terms, an additive increase of 10 decibels designates an increase in sound power by a multiple of 10.



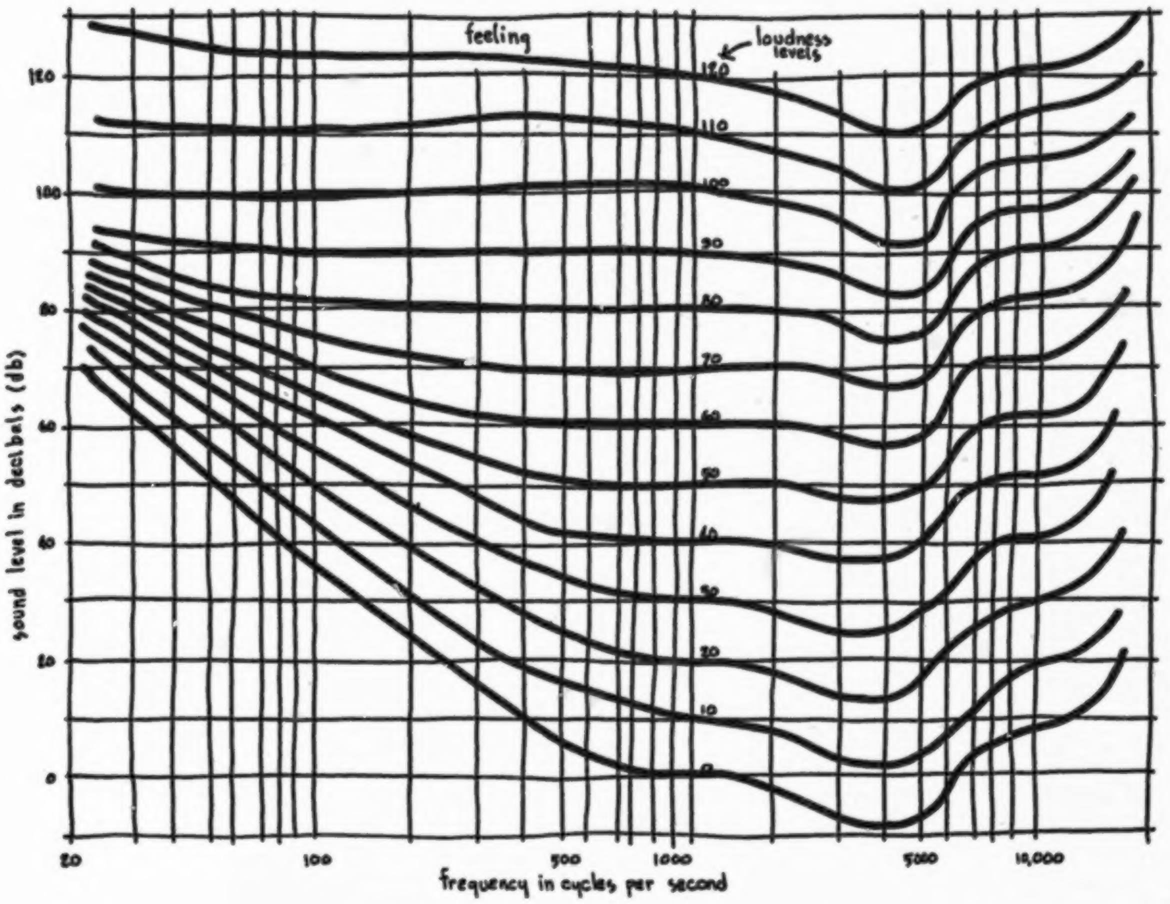
typical overall sound levels

1 (Note: Sources of diagrams and illustrations are keyed to the list found on page 99)

Because the decibel scale is a scale of multiples, there is a need to designate some base value as a beginning. By definition, 10 db represents 10 times as much power as zero db, but this is meaningless, unless there is agreement on what is to be considered zero db. A number of years ago zero db was standardized at 10^{-16} watts/square centimeter, or 0.0002 microbar. This was selected as a close approximation to the minimum threshold of hearing at 1000 cps.

The situation is further complicated by the fact that the ear is not equally sensitive to the various frequencies. In general terms, the ear is most sensitive between about 1000 cps and 5000 cps. These variations give rise to a need for units which measure the response of the ear. The units of "phons" and "sones" serve this purpose.

The phon is a measure of loudness level; it is numerically equal to the sound pressure level in decibels of a 1000 cps reference tone judged to be equal in loudness to the sound to be evaluated. For example, a 100 cps tone at 50 db is to the ear equal in loudness to a 1000 cps tone at 20 db; therefore each is rated at 20 phons. At the threshold of hearing (zero phons) the intensity varies from about 38 db at 100 cps to about -8 db at 3000 cps.



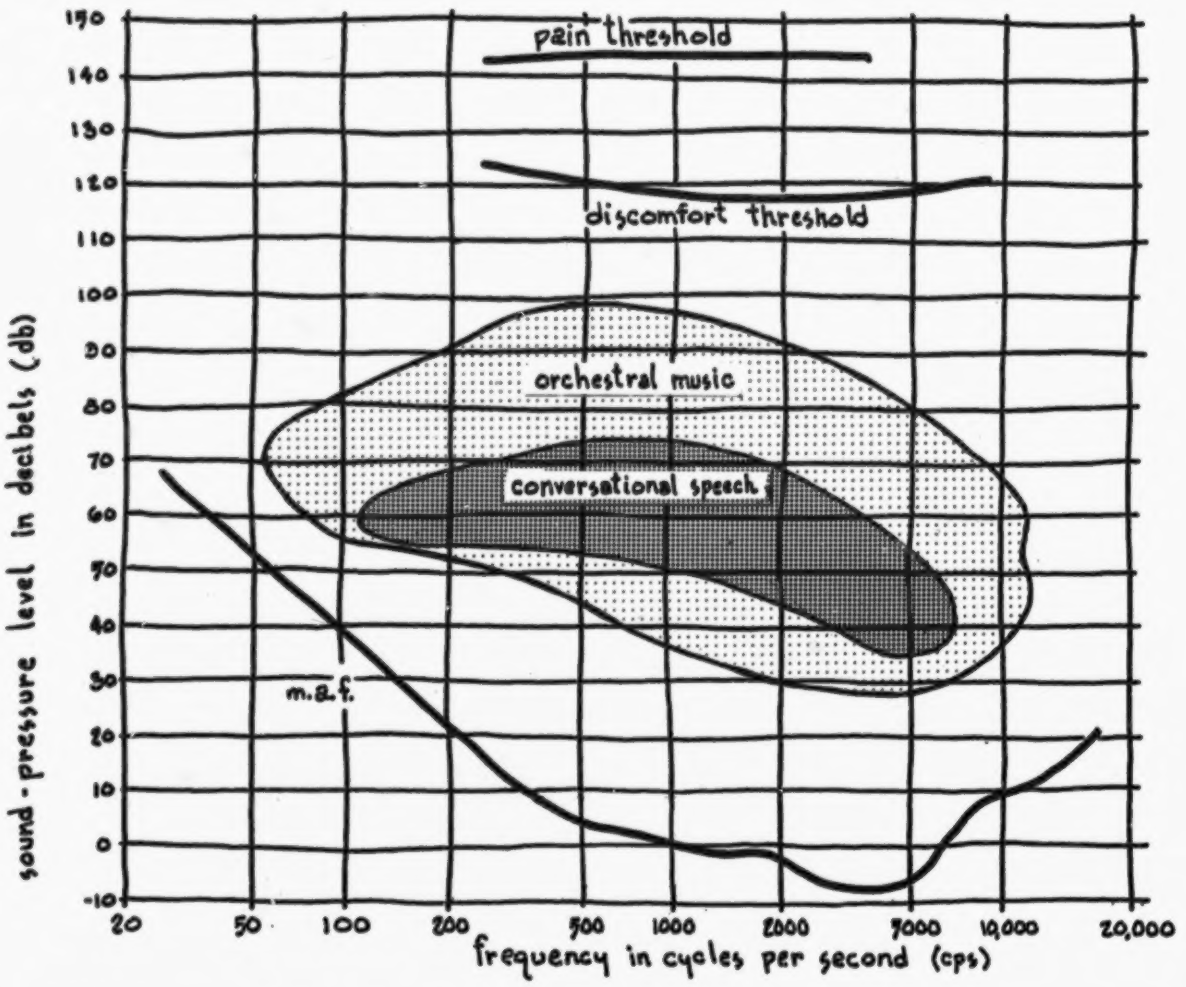
2

curves of equal loudness levels (phons) - all points on one curve will seem equally loud

The phon, however, does not produce a subjective uniform scale of increasing loudness. This is accomplished by a further conversion to a sone scale, designated as a unit of loudness, where 8 sones is twice as loud as 4 sones and 8 times as loud as one sone.

We can now define the spectrum of sound of particular concern in acoustical design. In frequency, the ultimate limits are 20 cps and 20,000 cps. Normal speech ranges from 100 cps to 7000 cps, with most of the power below 1000 cps. Orchestral music ranges from about 40 cps to 15,000 cps.

In loudness, sounds which are barely audible have a designation of zero phons. As the level increases, the upper limits occur at about 120 phons, where the energy is sufficient to feel the ear drum vibrations, and at 140 phons to cause pain. Conversation speech ranges from about 40 to 75 phons, and orchestra music from about 30 to 95 phons.



3

frequency-sound level variations: extremes and ranges for speech and music

Some additional units involved in acoustical work are:

absorption coefficient - a measurement of the sound-absorptive capability of a material. It is a dimensionless decimal fraction which measures the percentage of incident sound which does not reflect from the material.

noise-reduction coefficient - the average, to the nearest 0.05, of the sound-absorptive coefficients of a material at 250, 500, 1000, and 2000 cycles.

sabin - a unit of total absorptivity, equal to the product of square feet of surface and the absorption coefficient.

reverberation time - the time required for a sound in an enclosure to decay to 1/1000 of its original pressure, corresponding to a drop in sound-pressure level of 60 decibels.

The sound-survey meter is one of two measuring instruments likely to be employed in a not-too-technical analysis of noise levels in a school building. The meter is basically a device which indicates the level of noise in decibels. As a hand-held piece of equipment, it is quite small, light in weight, easy to use, and inexpensive.

The sound-level meter is a similar basic device for sound measurement. This meter also reads in terms of decibels. These instruments provide a rough adjustment for the variations of the sensitivity of the ear with frequencies corresponding to the intent of the "phon" and "sone" units. On an "A" scale setting the instrument response corresponds to the receptivity of the ear at a level of 40 phons; on the "B" setting it responds to the ear's receptivity at about 70 phons. A "C" scale gives a flat response without adjustment for frequency.

FUNCTION
LEVEL
OFF
WEIGHTING
70
80
100
decibels
SOUND-SURVEY METER
GENERAL RADIO CO.
CONCORD

sound survey meter

120
WEIGHTING
BATTERIES
METER
ON
UP
SOUND-LEVEL METER

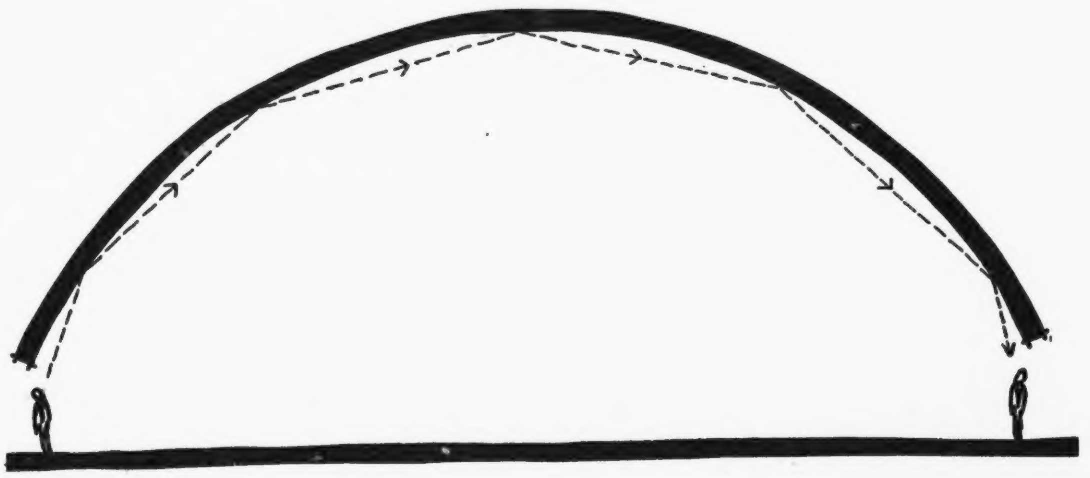
sound level meter

Other more sophisticated devices which would be used in a more detailed survey of acoustical environment include on octave-board noise analyzer, which is capable of analyzing noise having complex frequency components. Sound and vibration analyzer, impact noise analyzer, wave analyzer, and various types of noise recorders and generators are also available for detailed study requirements.

• OTHER CHARACTERISTICS OF SOUND

There are some characteristics of sound which do not lend themselves to the scientific, analytical process. These characteristics are just as real as the precisely measureable characteristics mentioned earlier, but unlike them can be defined and predicted only on the basis of experience with similar or near-similar situations. Some of these qualities can be identified as:

reflection at surfaces - it is important to note that sound waves will reflect off a surface at an angle equal to the angle of incidence. This assumes that the surface irregularities are smaller than the wavelength of the sound. Normally, a significant fraction of the sound energy is absorbed. However, at a grazing incidence, with a curved wall, sound will "creep" along the surface with very little loss.



4

sound creep

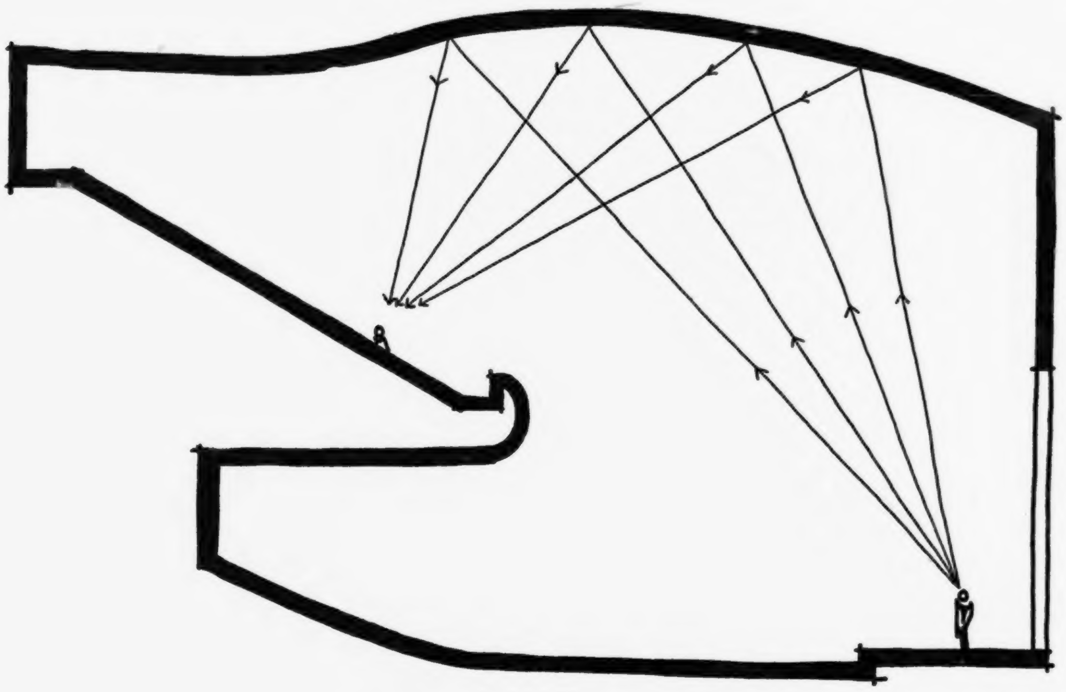
diffuse reflection - if the surface irregularities are of the order of the wavelength of the sound, or somewhat larger, the sound will be scattered and tend to have a diffuse distribution through the space. This is beneficial in avoiding defects such as echoes and providing a uniform sound level.

diffraction of sound through openings and around barriers - we commonly conceive of sound waves as moving in line-of-sight manner, leaving acoustical "shadows" behind barriers; however, sound waves also tend to spill around corners or move through openings and create an effect out of proportion to the size of the opening. This fact leads in part to a peculiarity of acoustical design:

control of sound or noise is only as good as the "weakest link" in the surrounding structural envelope.

directionality - another characteristic of sound is its directionality. The human ear is reasonably capable of identifying the point of origin of a generated sound by the differences in sound to the two ears and by the changes in sound with distance caused by viscous losses in the air.

focussing -still another characteristic is the focussing of sound waves. A domed ceiling or curved wall may act to reflect sound waves so that they converge at some point; a strong enough acoustical reflection may be created that the energy waves become excessively loud for a listener at that point. Such focussing is undesirable as it disturbs a uniformity of sound energy in a space.

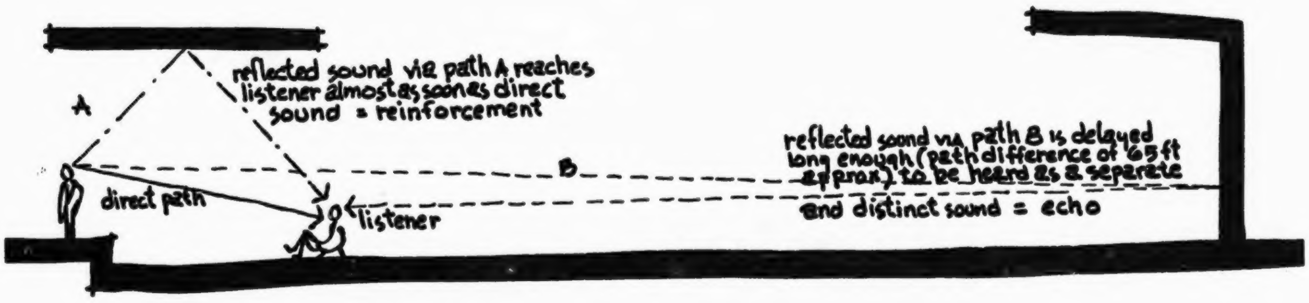


5

focussing due to room shape

masking - masking is defined technically as the amount by which the threshold of audibility of a sound is raised in the presence of another masking sound. Normally, masking is considered detrimental. However, masking noise or sound can be used to conceal unwanted, disturbing sounds. There are many cases in which it is easier to conceal unwanted sounds in this manner than to use a barrier construction with high transmission-reduction coefficients. A good example of the use of "acoustical perfume", as it is sometimes called, is the use of low-level music in office buildings to mask the more irritating sounds of talking or office machines; the same principle can be applied in some areas of school buildings.

echoes - echoes are a commonly understood phenonemon of sound. A separately heard reflected sound which reaches the ear with a time difference from the original sound of 0.058 seconds, or more, or a difference in distance of 65 feet or more, will be heard as an echo.


reflected sound via path A reaches listener almost as soon as direct sound = reinforcement
A
B
direct path
listener
reflected sound via path B is delayed long enough (path difference of 65 ft approx) to be heard as a seperate and distinct sound = echo

echo formation

human impairments - hearing impairments vary, of course, from person to person. It is not generally realized that a large proportion of the population does not have perfect hearing; most sensitivity losses are concentrated in high frequencies. In many cases, electronic techniques can be used to intensify sounds which an individual or group audience with defective hearing might otherwise lose.

environmental conditions - these conditions, such as temperature, humidity, and wind, also have an effect on sound transmission. Although the variation in speed is not great, sound travels somewhat faster in high temperature air. The effect of decreased humidity is to reduce somewhat the sound-transmitting capability of the energy waves in the air. Wind, which is the movement of masses of air molecules, can distort in a major way the wave front being transmitted through the air from some generating source.

2

ACOUSTICS AND ARCHITECTURAL PROGRAMMING

- PROGRAMMING – THE DEFINITION OF BUILDING REQUIREMENTS
- PROGRAMMING CONSIDERATIONS FOR SOUND QUALITY, SPEECH AND NOISE CONTROL
- REVERBERATION AND PROGRAMMING CONSIDERATIONS
- SUMMARY

LARGE TEACHING SPACES

• PROGRAMMING - THE DEFINITION OF BUILDING REQUIREMENTS

There is a step in school planning for which architects and administrators assume equal responsibility: the development of the building program. Simply put, the building program is a statement which translates the school's philosophy and goals into building requirements. It defines with words and diagrams the people and functions to be accommodated, the kinds of facilities needed, and their relationships to each other.

Programming is a complex process. It involves many groups often with conflicting or parochial interests - teachers, staff, administrators, taxpayers, other "influential" groups and committees. It involves complex, often conflicting statements of goals, philosophy and policy. It involves complicated financial, political and administrative factors. It involves hard work and diplomacy. For these reasons programming is often forfeited in favor of arbitrary, or insufficiently considered, decisions.

The building program should give the architect all basic necessary information about the building to be designed. It should include:

- a clear statement of the institution's educational philosophy, and its significance for the proposed building.

- an analysis of how the building is to function. This includes information about access, circulation, and overall servicing needs.
- a description of how each of the spaces will relate to each other and to the building as a whole.
- a schedule of every desired space in the building defining the types of users, number of users, functions to be housed, required square footages, necessary furniture, required equipment, supporting functions and all special requirements.

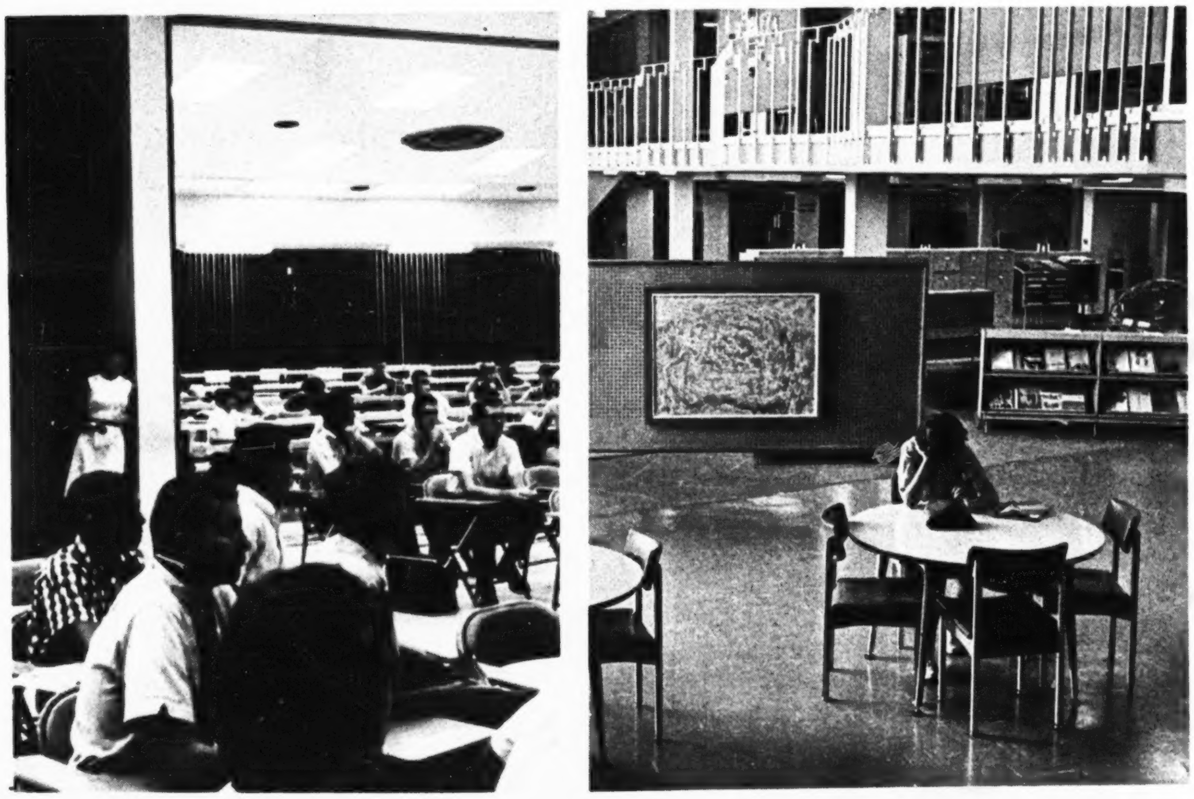
To be complete the school building program should also include desired environmental performance levels for the plant generally, and for special spaces specifically. For instance in defining the thermal environment, the program should spell out desired ranges for temperature and humidity for the school generally, and even more specific requirements for auditoriums, lecture rooms, gymnasiums, cafeterias, and dressing rooms. Likewise the visual environment would be defined by prescribing desired levels and quality of light for various tasks.

Following this approach the desired acoustical environment should also be defined in the building program. These considerations will relate to the site, to the building generally, and to various spaces specifically. For instance, the building program would:

- describe sources of off-site noise, such as highways or commercial areas, and prescribe acceptable noise levels within the school building. In his design, the architect must see that the off-site noise is controlled and reduced by appropriate sound barriers.
- note noise-producing activities which must be accommodated on the site and the problems of location for acoustical compatibility.
- define acceptable noise levels for corridors, lobbies, and other circulation areas.
- describe the kinds of functions an auditorium will be expected to house - lectures, motion pictures, plays, choral music,

instrumental music, or whatever - and therefore the acoustical characteristics it must exhibit.

- note classroom uses of instructional aids and media - films, records, television - and the accompanying acoustical planning considerations.
- define acoustical qualities for general classrooms in terms of allowable ambient noise and desirable reverberation time.



planning for varying acoustical requirements in multi-use spaces

All such acoustical concerns should be considered at one stage or another in the design process. However, the programming phase is the time to define desired levels of acoustical performance, levels of performance which must be met subsequently during design.

• PROGRAMMING CONSIDERATIONS FOR SOUND QUALITY, SPEECH AND NOISE CONTROL

The quality of sound within a space is established by the various frequencies and the intensity and duration of these frequencies which go to make up a sound. In only a few cases is a single frequency heard by itself; a whistle produced by a person is approximately a pure, single frequency. The difference in character or quality of various musical instruments, all sounding the same note, is determined by the combination of frequencies - harmonics and overtones - which are characteristic of the resonant qualities of the instrument. The ear receives the various frequencies, and the variations and combinations of frequencies then become, to the listener, an interpretation of quality.

The quality of sound in a room is determined by what happens to the various frequencies in their paths of travel from the source to the ear of the listener. It is inevitable that they will be changed, and generally the interpretation is that they have been improved. An illustration of this is that music is generally considered to sound better in an enclosure than it does out-of-doors.

There are three basic ways by which a sound is changed. The first, of importance only in large spaces, is the selective absorption of frequencies by the air. Below frequencies of 1000 cps, air absorption is small, but for high frequencies with low relative humidity, the absorption over a long distance can be appreciable and will distort the nature of the sound.

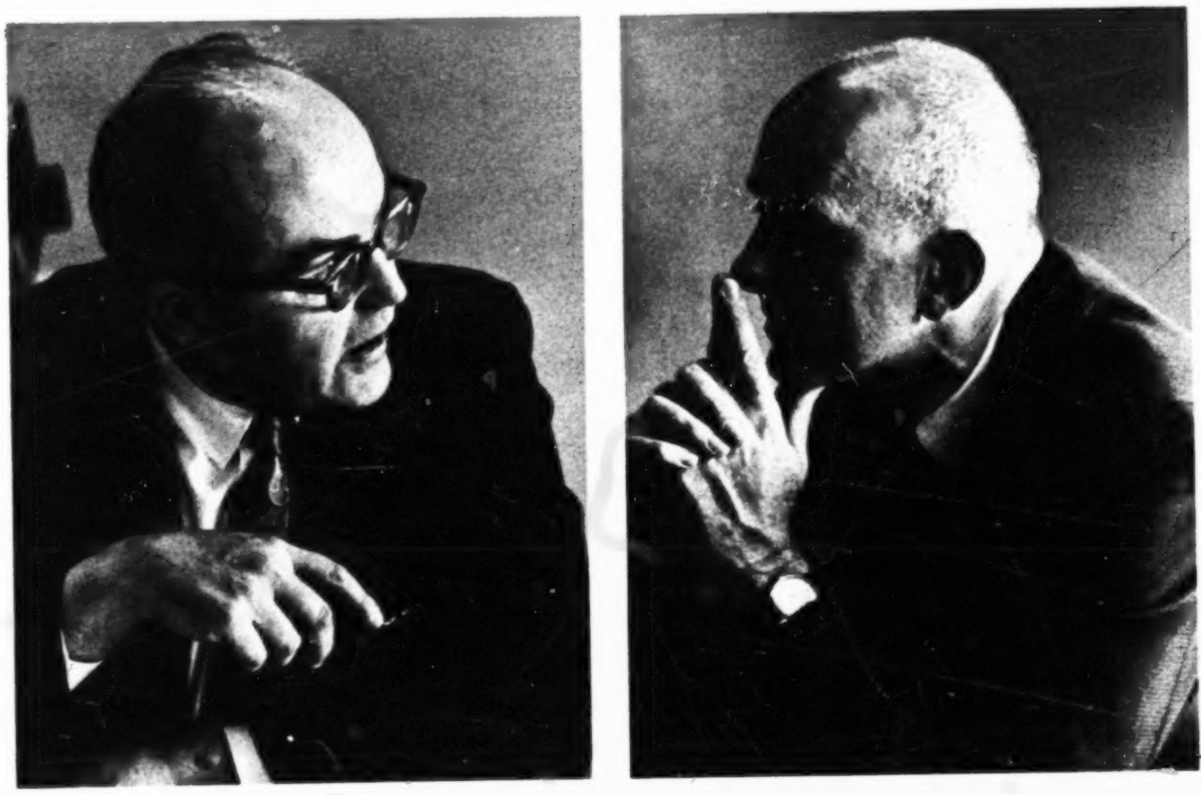
The second is the selective absorption of frequencies by the surfaces of a room. Every reflective and absorptive material effects frequency, but most porous absorbers, such as common acoustical tiles, are much more absorptive at high frequencies than at low. Such absorption further effects the quality of sound coming to a listener.

The third, even more subtle and pervasive, is the effect of the resonant characteristics of the elastic volume of air which forms the room. As with any elastic body, this volume has certain natural resonant modes. If this elastic volume is activated by the introduction of sound into the room, it will respond in a selective manner such that the resonant frequencies will be emphasized and the quality of the sound will be, in part, produced by the volume of the room itself. Unfortunately, this aspect of room acoustics is extremely complex, and, in the present state of the art, is not subject to analytical treatment. Some work is being done in this area with acoustical models.

Program specifics on selective absorption by air and by room surfaces are taken care of by reverberation time computations and the recommended reverberation times for different frequencies. These are discussed in a later section.

Separate from the quality of sound is the specific ability to understand speech - a major activity in the functioning of a school.

The nature of speech is that of a succession of widely differing sounds, interspersed with pauses and modified by accents and inflections. Roughly, but not exactly, the individual sounds correspond to syllables. In some cases, a changing sound is inherent in the sound itself such as "oi" in "noise"; other kinds of sound include, for example, the hissing noise of an "s", the explosive sound of a final "t", and the sustained sound of vowels such as "a".



The various speech sounds are of widely different power and frequency. In general, vowels and voiced consonants - sounds which require the vocal cords and are sustained - have much greater power than sounds made solely by air forced between the lips and teeth, such as "s" and "t". Also, voiced sounds are of much lower frequency than those formed only with lips and teeth. The management of these variables is important in designing for speech communication. Fortunately, absolutely perfect syllable identification is not necessary for satisfactory communication; all sounds need not be heard in order to convey meaning. In general a person uses sensory stimuli to come to conclusions even though the information is incomplete. Just as one does not need to see the doorknob to conclude that a distant object is a building, so a student does not need to hear every speech sound to draw meaning from things said by a teacher.

The capability of a room to transmit clearly individual sounds is measured by Percentage Syllable Articulation. Examination of this room characteristic requires that meaning be eliminated from the testing process, in order to eliminate "fill-in" identification from context. Rather, a room is rated in terms of whether or not specific sounds are heard; the process consists of a speaker reading meaningless syllables from a series of standard test sounds, so distributed that each occurs with approximately the regularity involved in normal speech. Listeners in the room being tested determine whether or not they have detected the individual sounds. The sounds are separated into vowel and consonant types, and the results of these tests are considered in the following formula:

$$PA = 100\left[1 - (1 - VwCw^2)^{0.9}\right]$$

PA = Percentage Syllable Articulation

Vw = Fraction of vowels correctly heard

Cw = Fraction of designated consonants correctly heard.

The test imposes on sounds the reverberant characteristics of the room, and different speakers and listeners are used to average the results. This becomes a reasonable measure of the speech-quality of the space, and leads to the acoustical rating of its design.

However, there is a special problem in designing schools where some speech originates with children who may have weak voices and may pronounce and enunciate poorly. Teachers should, and usually do, develop an ability to speak effectively and with adequate volume. Sometimes there are acoustical weaknesses in a room which teachers are in the best position to understand and to correct.

Reverberation, for example, can be controlled by the selection of furnishings; chairs, desks, rugs, bookcases and draperies can have a reducing effect on reverberation time. Significantly, all are subject to change by school administrators. It seems reasonable that the significance of acoustics should lead administrators to assigning rooms for specific purposes and to plan the furnishing of these rooms partly in terms of creating most advantageous acoustics. In remodeling old schools, acoustical problems may be solved more effectively by furnishings, than by permanent construction changes.

Program specifics affecting speech communication have to do with reverberation time and the shape of the space and the location of absorptive and reflective materials.

Reverberant sound acts as reinforcement for weakness in the power of direct sound, but an excessive delay in reverberant sound paths tends to jumble and mask the individual sounds. The shape of the space and a proper location of reflecting surfaces are vital in distributing speech sounds adequately to an audience. More detail on each of these factors is provided in later sections.

The effect of noise is a major consideration when programming educational facilities. Noise confuses and masks speech sound and causes major harm to any musical program. It can be an annoyance and detriment to study and concentration.

When noise and speech reach the ear at the same time, the ear drum and the hearing mechanism must respond to both, and the brain must sort out the meaningful sound from the noise. Considering the conglomeration of sounds that continually come to the ear, this process of concentrating on wanted sounds is amazingly efficient. It does have limitations, however, particularly for the critical listening involved in the educational process.

Contrary to the common view, noise has beneficial as well as detrimental effects. Disturbance and distraction from noise are more a result of the nature of the noise than of its level, assuming it is within some reasonable range, and the deliberate use of a bland, constant noise can be a benefit in concealing an intermittent and distracting noise.

In an unusually quiet environment, otherwise unnoticed sounds such as electric switch operation, plumbing noises, fluorescent ballast hum, and the sounds of a typewriter force themselves on one's attention. In an area near a dividing partition, the sounds from an adjacent classroom will distract a student's attention. The simplest solution may not be an increased value to the barrier against intruding noise, but the provision of a masking, non-information-carrying, and therefore non-distracting, background noise.

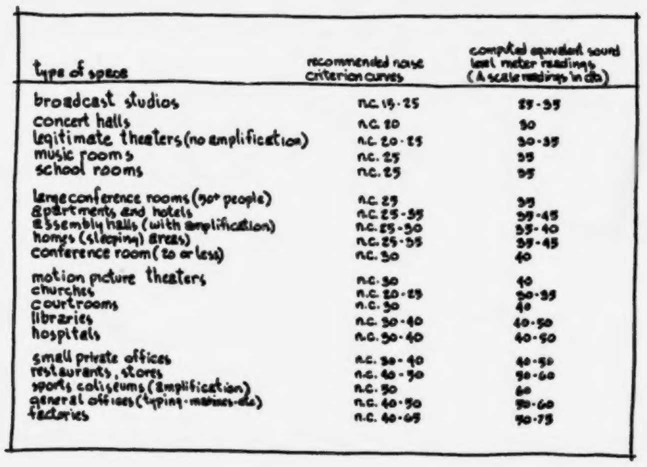
Connected with this idea is the factor that a speaker - a teacher - adjusts his voice level to what he, more or less unconsciously, senses is necessary in order to be heard. A background noise used to mask and conceal intermittent noise will be, in part at least, counteracted by an increase in the level of wanted sound.

For this reason the room arrangement should locate the speaker near any source of noise, and it would be an advantage to have teachers "back-to-back" on the two sides of a dividing partition. In this way one could avoid having students in the back of a room, where the teacher's voice level may be low, hear and be disturbed by a teacher conducting a class immediately on the other side of a relatively poor dividing partition.

Program requirements must take into account the variable effects of noise frequencies. An approximation is provided by designating maximum levels in terms of the "A" scale readings of a sound level meter.

A more precise method uses Noise Criterion Curves (NC) or the NCA modification which designates maximum acceptable levels. The permissible levels differ with frequency, but, significantly, tend to indicate minimums as well as maximums. In other words, the background noise should not be above these levels at the various frequencies, nor, to adequately mask distracting sounds, should they be substantially below these values. Often, the selection of grilles or other air-handling apparatus can be used to provide this background "acoustical perfume". An excellent discussion of the design procedure is contained in the Guide and Data Book of the American Society of Heating, Refrigeration and Air-Conditioning Engineers.

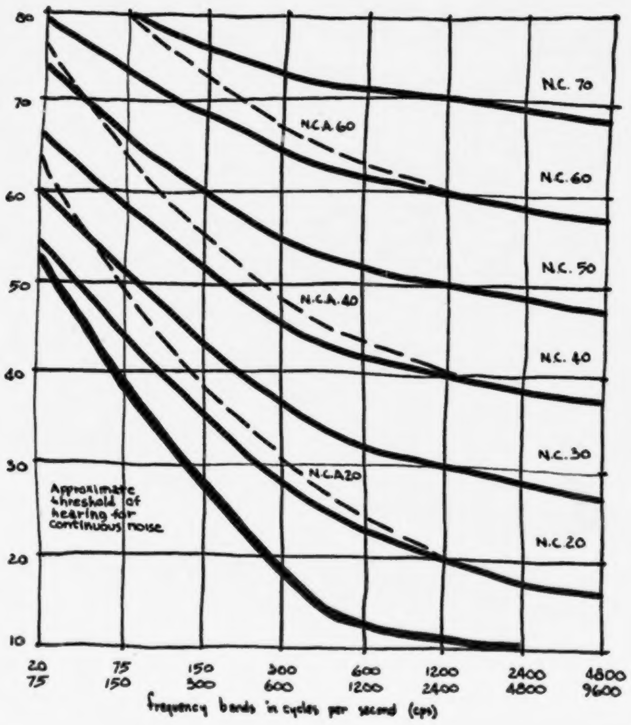
6



type of space	recommended noise criterion curves	compiled equivalent sound level meter readings (A scale readings in db)
broadcast studios	n.c. 15-25	25-35
concert halls	n.c. 20	30
legitimate theaters (no amplification)	n.c. 20-25	30-35
music rooms	n.c. 25	35
school rooms	n.c. 25	35
large conference rooms (50+ people)	n.c. 25	35
apartments and hotels	n.c. 25-35	35-45
assembly halls (with amplification)	n.c. 25-30	35-40
homes (sleeping) areas)	n.c. 25-35	35-45
conference room (20 or less)	n.c. 30	40
motion picture theaters	n.c. 30	40
churches	n.c. 20-25	30-35
courtrooms	n.c. 30	40
libraries	n.c. 30-40	40-50
hospitals	n.c. 30-40	40-50
small private offices	n.c. 30-40	40-50
restaurants, stores	n.c. 40-50	50-60
sports coliseums (amplification)	n.c. 50	60
general offices (typing-machines-etc)	n.c. 40-50	50-60
factories	n.c. 40-65	50-75

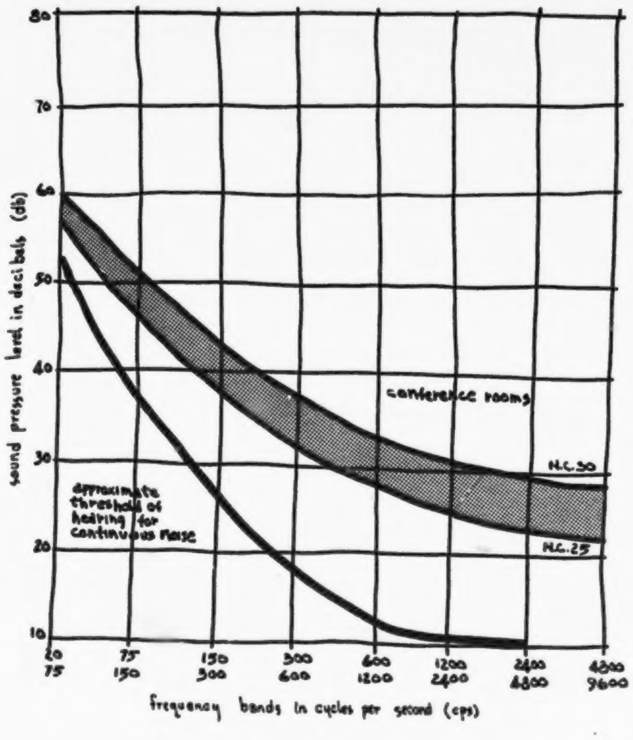
a listing of recommended noise criterion curves for typical facilities with equivalent sound level meter readings

7



noise criterion curves

8



range of recommended noise criterion curves for conference rooms

ARCHITECTURAL PROGRAMMING

Of the range of acoustical problems, noise requires consideration at the earliest point and is a continuing part of the planning and decision making process.

A poor site selection can make noise problems unsolvable in any reasonable fashion; intelligent application of principles of noise control can reduce markedly the cost of necessary barriers against unwanted sound. In distributing on the site the various units and functions, similar benefits can be obtained from knowledgeable design solutions. An approach is provided by the following classification of typical spaces:

Category I — low noise generation, low noise tolerance

- library
- classroom
- study area
- seminar room

Category II — high noise generation, low noise tolerance

- music room
- lecture hall
- audio-visual room
- auditorium

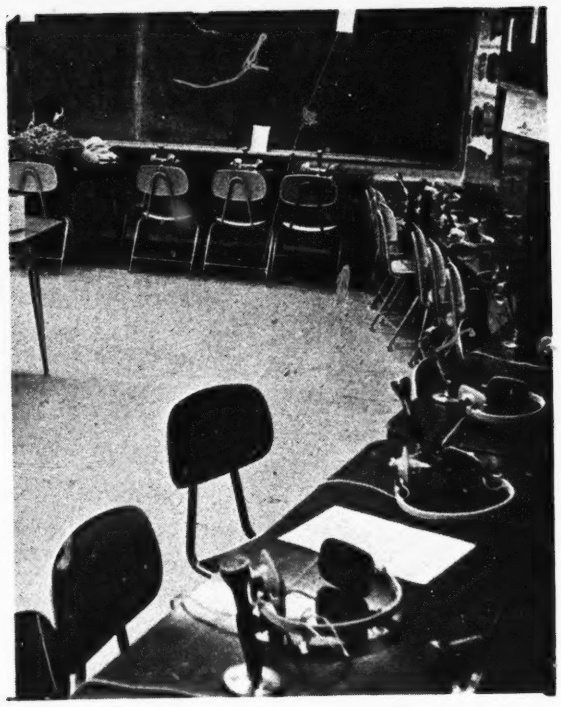
Category III — high noise generation, high noise tolerance

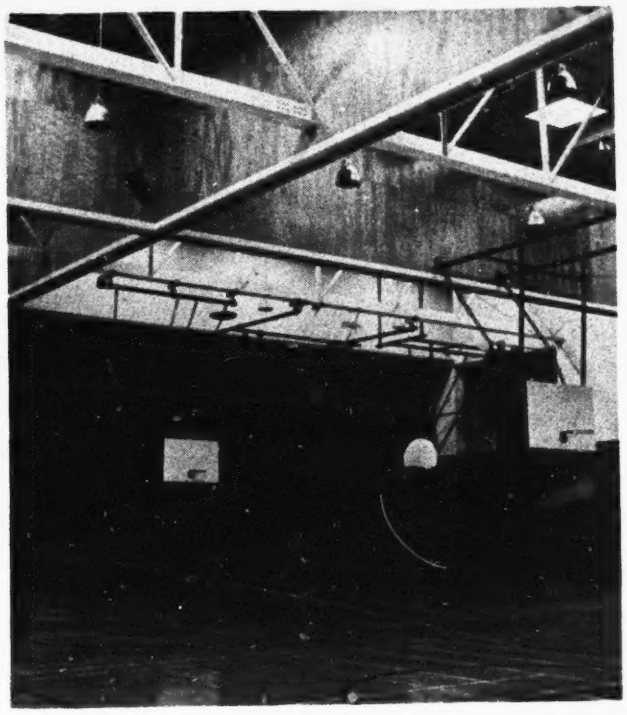
- gym
- locker room
- shop
- corridor
- commons
- service area
- cafeteria

Categories I and III indicate generally spaces which, within the category, can be grouped without serious problem, but a library (Category I) should be well removed from a gym (Category III) to avoid the need for expensive sound-insulating construction.

Category II presents special problems. An auditorium may best be located as a distinct and semi-separate plan unit. Lecture halls and audio-visual rooms may require locations dictated by circulation problems and will vary in the degree of acoustical difficulties.

Music practice and classrooms tend to be grouped for clarity of function, but the critical listening inherent in good music, and the interference from adjacent music rooms cause problems of great difficulty. Later parts of this study will indicate methods of coping with these problems in terms of planning, and the remaining transmission difficulties will probably require sound-insulating divisions between spaces.





Corridors offer special noise problems. They act as an insulator or sound lock between classrooms - as apparent in the open-plan arrangement. But they can be a source of noise, and, unless adequately treated with sound absorbing material, can conduct sound along their length.

The problem of noise originating in corridors is aggravated by scheduling on a modular-time basis where students are moving in the corridor at a time when classes are being conducted in adjacent classrooms. In these instances positive efforts must be made to reduce noise generation, by use of carpeting to avoid the scuffle of feet and by general application of absorption to the floor and upper walls.

Designers should be conscious of the cumulative effect of noise. Students talking in a corridor will raise their voices to overcome the chatter from other students, thus adding to the general level and causing the others to increase their level of speech. In reverse, heavy absorption not only absorbs sound energy which exists, but reduces the level produced.

The psychological aspect of background noise is only partly understood. However, it seems certain that a person relates to his environment, to a substantial degree, through acoustical characteristics and that this is an important part of producing appropriate surroundings for various activities.

Complete absence of sound can be almost as disturbing as a complete absence of light. A room isolated and deadened for test purposes demonstrates the reliance humans place on sound as an interpreter of environment; the ability of a blind person to use sound for these purposes illustrates the importance of environmental acoustics.

Visits to some open-plan schools seem to indicate possible positive benefits to the sense of busy-ness and activity contributed by lack of full acoustical separation between spaces. In a recently completed school near Chicago classes were conducted side-by-side, with only visual separation, and with apparent satisfaction and success, although there was a general high background sound level. Both teachers and students needed to become accustomed to this environment, but this adaptation seems to have been made, and the students may subconsciously prefer this to the forced isolation of a closed room.

In another school in the same area, folding partitions were used as space dividers to form individual classrooms. The teachers deliberately left these open a foot or more, explaining this in terms of being able to supervise, on occasion, two rooms at once. Whether or not this also functions to counteract an uncomfortable isolation of a class group is debatable, but it does indicate that absolute acoustical separation is not a necessity.

• REVERBERATION AND PROGRAMMING CONSIDERATIONS

There is a serious lack in acoustics of rigorous analytical and design procedures. The one common formula, widely used in design, is the formula for reverberation time:

$$t_{60} = \frac{0.049V}{S[-2.3 \log (1-\bar{\alpha})] + 4mV}$$

t_{60} - reverberation time in seconds: the time required for sound in a room to decay through a range of 60 db.

V - volume in cubic feet

S - surface area in square feet

$\bar{\alpha}$- average absorption coefficient

m - an attenuation coefficient which accounts for the viscous losses in the air. Except in large spaces, these losses can be ignored.

Reverberation is the persistence of sound in an enclosure, after the source has stopped, as a result of multiple reflections from the boundaries. It has both beneficial and detrimental aspects.

A listener in an enclosure receives at one time both direct and reverberant (reflected) sound. Without the reverberant characteristic the sound would be thin and weak, similar to unamplified outdoor speech; reverberation adds richness and power, a characteristic much cherished, and sometimes abused, as may be illustrated by the use of an electronic "reverb box" for teenage electric guitar.

But, by definition, a reverberant sound follows the same direct sound by some detectable period of time, and if a specific sound persists too long, it will confuse and mask the other sounds which follow. It is for this reason that conversation across a large, reverberant gymnasium is almost impossible.

The rapid succession of speech sounds, and the need to detect the separate sounds, causes a need for a relatively short reverberation time for voice communication - a range of about 0.6 to 1.8 seconds.

At the other extreme, choral and organ music require the blending caused by the sustaining of sound, and benefit by the richness of reverberant spaces. A reverberation time of 3 to 4 seconds can be beneficial. For operettas, recitals, and similar programs, intermediate values are appropriate. The need for reinforcement of sound levels tends to lead to longer reverberation times for larger spaces.

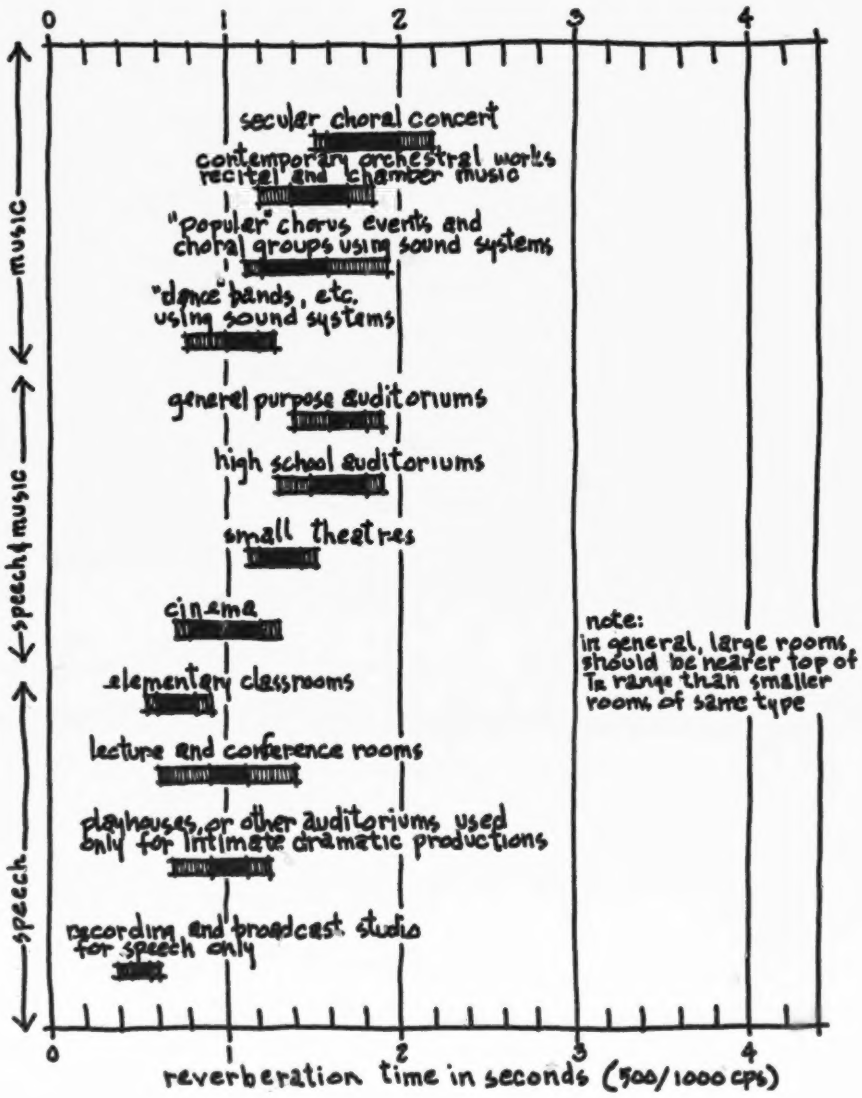


chart of appropriate reverberation times for various types of facilities

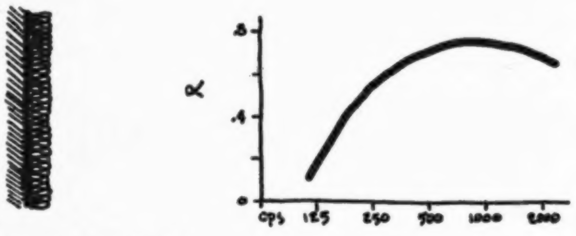
9

Sound quality is affected by the richness of reverberant sound - and by the selective absorption of sounds of various frequencies. The attenuation coefficient "m" adjusts for selective air absorption, and the differing values of the absorption coefficent "α" adjusts for the selective absorption by room surfaces.

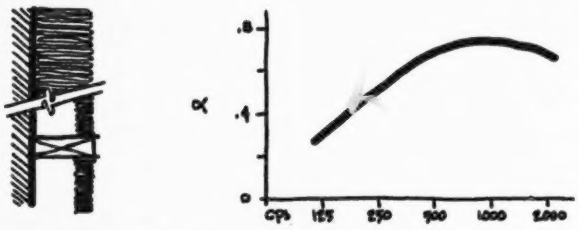
The reverberation time is, therefore, different at various frequencies and tends to be lowest for those frequency ranges where the surfacing material or the air are most absorptive.

materials	coefficient					
	125cps	250	500	1000	2000	4000
• brick, unglazed	0.03	0.03	0.03	0.04	0.05	0.07
• brick, unglazed, painted	0.01	0.01	0.02	0.02	0.02	0.03
• carpet, heavy, on concrete	0.02	0.06	0.14	0.37	0.60	0.65
• same on 40oz. hair-felt or foam rubber	0.08	0.24	0.57	0.69	0.71	0.73
• same with impermeable latex backing	0.08	0.27	0.39	0.34	0.48	0.63
• concrete block, coarse	0.36	0.44	0.31	0.29	0.39	0.25
• concrete block, painted	0.10	0.05	0.06	0.07	0.09	0.08
fabrics						
• light velour, 10oz./sq.yd hung straight in contact with wall	0.03	0.04	0.11	0.17	0.24	0.35
• medium velour, 14oz/sq.yd draped to half area	0.07	0.31	0.49	0.75	0.70	0.60
• heavy velour, 18oz/sq.yd. draped to half area	0.14	0.35	0.55	0.72	0.70	0.65
floors						
• concrete or terrazo	0.01	0.01	0.015	0.02	0.02	0.02
• linoleum, asphalt, or cork on concrete	0.02	0.03	0.03	0.03	0.03	0.02
• wood	0.15	0.11	0.10	0.07	0.06	0.07
glass						
• large panes of plate glass	0.18	0.06	0.04	0.03	0.02	0.02
• ordinary window glass	0.35	0.25	0.18	0.12	0.07	0.04
• gypsum board, 1/2" nailed to 2x4's 16"oc.	0.29	0.10	0.05	0.04	0.07	0.09
• marble or glazed tile	0.01	0.01	0.01	0.01	0.02	0.02
• plaster, gypsum or lime smooth finish on tile or brick	0.13	0.15	0.02	0.03	0.04	0.05
• same, rough finish on lath	0.02	0.03	0.04	0.05	0.04	0.03
• plywood panelling, 5/8"	0.28	0.22	0.17	0.09	0.10	0.11

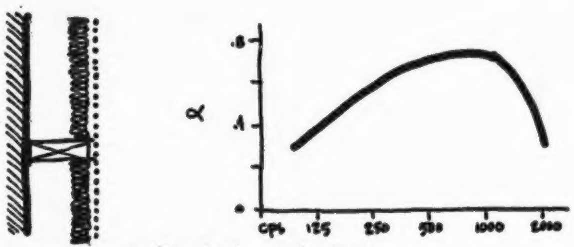
10 *table of absorption coefficients for various materials*



thin porus material



thick porus material or thin material with airspace



porus material with protective perforated facing

spectrum curves of absorption for various constructions 11

However, uniform absorptivity and reverberation time are not ideal. Because of the beneficial warmth of bass tones, and because of the lesser sensitivity of the ear to the lower frequencies, a longer reverberation time is desirable for frequencies below 500 cps. Adjustments can be made by adjusting the recommended reverberation time at 500 cps by the following factors:

frequency (cps)	multiplier
400	1.03
300	1.10
200	1.23
100	1.52

With this data, and with information available from manufacturers and others, it is possible to select materials with proper frequency-absorption characteristics and thus control the sound quality. This is beneficial, of course, for speech, but quite important in rooms designed for music.

• SUMMARY

Communication lies at the heart of the teaching process, and a large part of communication in a school is through the medium of sound; a school which hampers audio-communication has failed in a primary purpose.

Speech is a direct and obvious communicative method, and a skill in communication by speech should be part of the instruction. The spaces which transmit speech sounds need form and treatment which aid in this process.

Music is a more subtle means of communication and requires greater attention to quality and conditions for critical listening. Important musical spaces often require specialized knowledge in acoustics.

Noise, as environmental sound, is a means of background and perhaps subconscious communication with the surroundings. It is also a possible major detriment to music and speech. Additional studies are needed on the effects and control of noise, and those concerned with school design should be alert to experiments in this field.

The following table is an attempt to summarize a few basic ideas. It should not be considered more than this, and it is perhaps an over-simplification of a very complex subject. It may, however, be a starting point in the understanding of design for acoustical control.

Table I - expected masking noise (emn)

frequency in cps.	63	125	250	500	1000	2000	4000	8000
no ventilation: rural	48	36	30	25	15	15	15	15
no ventilation: urban	58	49	41	35	31	29	28	27
low velocity diffusers: rural	48	36	30	25	20	19	15	15
low velocity diffusers: urban	58	49	41	35	31	29	28	27
high velocity diffusers: rural	48	36	30	25	30	29	24	17
high velocity diffusers: urban	58	49	41	35	31	29	28	27
induction units: rural	48	36	30	29	30	29	24	17
induction units: urban	58	49	41	35	31	29	28	27
fan coil units: rural	48	36	32	34	35	33	29	27
fan coil units: urban	58	49	41	35	35	33	29	27

12

key

shape recommendations	absorption recommendations	notes
a. avoid - circular plans, vaulted ceilings & domes	a. sound absorbing ceiling/___%	n.p. - no problem
b. non-parallel side walls	b. sound absorbing 2 adjacent walls/___%	n.i. - not important
c. non-parallel ceiling and floor (unless absorb.)	c. absorption on distant walls/___feet	n.r. - not relevant
d. sloped floor	d. absorption on back wall	
e. splayed platform side walls	e. carpet floor	
f. 2 adjacent walls splayed	f. interrupting furniture and/or draperies	
g. analyze by ray diagram		

acoustics as a primary consideration

	acceptable noise level (n.c.)	expected masking noise (e.m.n.)	recommended reverberation time (sec.)			absorption recommendations	shape recommendations	remarks
			250 cps	500 cps	1000 cps			
classroom (lecture)	35	table 1	-	0.5-1.0	-	a/50	a.	wall-mounted loudspeaker
lecture room (60-)	35	table 1	-	0.5-1.0	-	c/40	ab	wall-mounted loudspeaker
lecture room (60-150)	35	table 1	-	0.8-1.0	-	d	abd	central sound system
lecture room (150-500)	30	table 1	-	0.8-1.2	-	c/50 d	adeg	central sound system
auditorium (500-)	25	table 1	1.4-1.6	1.0-1.4	1.0-1.4	c/70 d	aeg	central sound system watch for echoes
auditorium (500-1000)	25	table 1	1.4-1.8	1.2-1.6	1.2-1.6	c/70 d	ag	full frequency central system watch for echoes
language laboratory	30	table 1	-	-	-	a/100	a	necessary laboratory equipment gasketed doors - double glazed windows
band rehearsal room	30	table 1	0.6-0.8	0.5-0.8	0.5-0.8	a/100 b/100	abc	recording facilities desirable
orchestra rehearsal room	30	table 1	0.6-0.8	0.5-0.8	0.5-0.8	a/80 b/50	abc	recording facilities desirable
choral rehearsal room	30	table 1	0.4-0.8	0.5-0.8	0.5-0.8	a/70 b/50	abc	recording facilities desirable
ensemble studio	30	table 1	0.6-0.8	0.5-0.8	0.5-0.8	a/100 b/50	b	-
practice rooms	35	table 1	-	-	-	a/100	b	deep sound absorbing panels = ½ floor area
music classrooms	35	table 1	0.6-1.1	0.5-0.8	0.5-0.8	a/100 b/50	cf	-
preview room	35	table 1	0.6-0.8	0.5-0.8	0.5-0.8	a/100 b/50	cf	sound reproduction equipment required
t.v. studio	45	table 1				-	n.p.	special equipment required - deep sound absorption on all walls and ceiling

acoustics as a secondary consideration

	acceptable noise level (n.c.)	expected masking noise (e.m.n.)	recommended reverberation time (sec.)			absorption recommendations	shape recommendations	remarks
			250 cps	500 cps	1000 cps			
classroom (non-lecture)	35	table 1	-	0.5-1.0	-	a/100	a	-
gymnasium	45	table 1	-	0-1.5	-	-	-	distributed sound systems for announcements central speech system desirable
corridor	45	table 1	-	-	-	a/100 e	n.r.	downward facing speakers for paging
office	35	table 1		0-1.0		f	n.i.	-
lounge	35	table 1	-	-	-	a/100 ef	n.i.	-
lobby	45	table 1	-	-	-	-	n.p.	long reverb. time gives monumental character sound amp. and absorption for paging
swimming pool	45	n.r.	-	0-1.5	-	a/100	-	chlorine and moisture resistive absorb. materials paging system desirable - overhead of audience
laboratory	35	table 1	-	-	-	a/100	n.p.	-
machine shop	45	table 1	-	-	-	a/100	n.p.	-
electrical shop	45	n.r.	-	-	-	a/100	n.p.	-
carpentry shop	45	table 1	-	-	-	a/100	n.p.	-
locker room	45	table 1	-	-	-	a/100	n.p.	-
interview room	35	table 1	-	-	-	a/100 e	f	-
secretarial classroom	35	table 1	-	-	-	a/100	n.p.	don't locate over critical rooms unless special impact floor construction is used.
cafeteria	40	n.r.	-	-	-	a/100	n.p.	distributed sound system with zone switching if use for lectures or background music.
cafeteria serving area	40	n.r.	-	-	-	a/100	n.p.	-

13

ARCHITECTURAL PROGRAMMING

space	acce[illegible] noise	expected masking noise(a.m.n.)	recommended reverberation time (sec)	absorption recommendations	shape recommendations	remarks
shower room	45	tableI	n.p.	–	n.p.	–
mech.equipment room	n.r.	n.r.	n.r.	–	n.r.	take proper precautions with mounting to avoid structure-borne vibrations.
boiler room	n.n	n.r.	n.r.	–	n.r.	don't locate near critical spaces - beware of rumble, draft, or fan noise
janitor's closet	n.n.	n.n	n.r.	–	n.r.	don't locate near critical spaces
recieving room	n.r.	n.n	n.r.	–	n.r.	don't locate near critical spaces
kitchen	45	n.r.	–	3/100	n.p.	–
refrigeration room	n.r.	n.n	n.r.	–	n.r.	isolate equipment from critical spaces

acoustics unimportant

3

ACOUSTICS AND SCHOOL PLANNING

- ACOUSTICS AND THE PLANNING PROCESS
- ACOUSTICS AND SITE
- ACOUSTICS AND PLAN TYPES

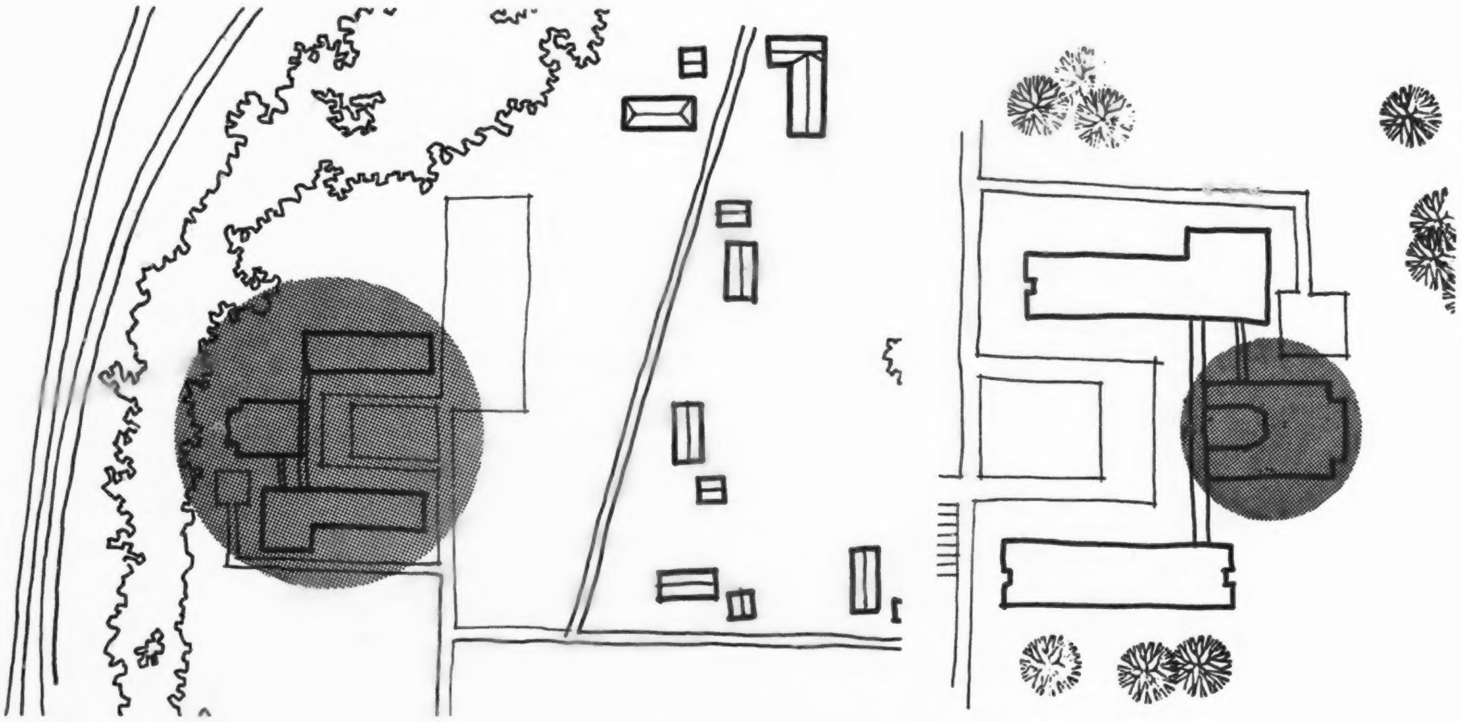
ACOUSTICS AND THE PLANNING PROCESS

An architectural program provides the base from which the building design develops. Its essence is a statement of the purposes for the architectural project. For a school building, of course, the basic purpose is communication.

School design which hampers audio-communication has failed in fulfilling one primary purpose for the building. However, it is insufficient to think in terms of avoiding poor acoustics; rather, available skills and technology should provide a design in which the acoustical characteristics consciously and deliberately contribute to and enhance the activities in the various spaces of the school. To accomplish this goal, consideration of acoustical needs should be part of the development of the project from programming through the stages of design to construction and equipment installation.

With acoustical performance requirements defined for him in the architectural program, the architect then has available to him a number of opportunities during planning and design to accomplish them. When first considering the building site and its location, acoustical concern may focus on the existence of an unsatisfactory ambient sound level. The source may be a nearby highway, mill, or commercial zone; the response may be the avoidance of the noise source or reducing the noise-transmission to a satisfactory level.

Each of these alternatives has several ramifications. Avoidance of the noise source may consist of rejecting the proposed site entirely or using the depth of the property to shield the building from off-site noise.

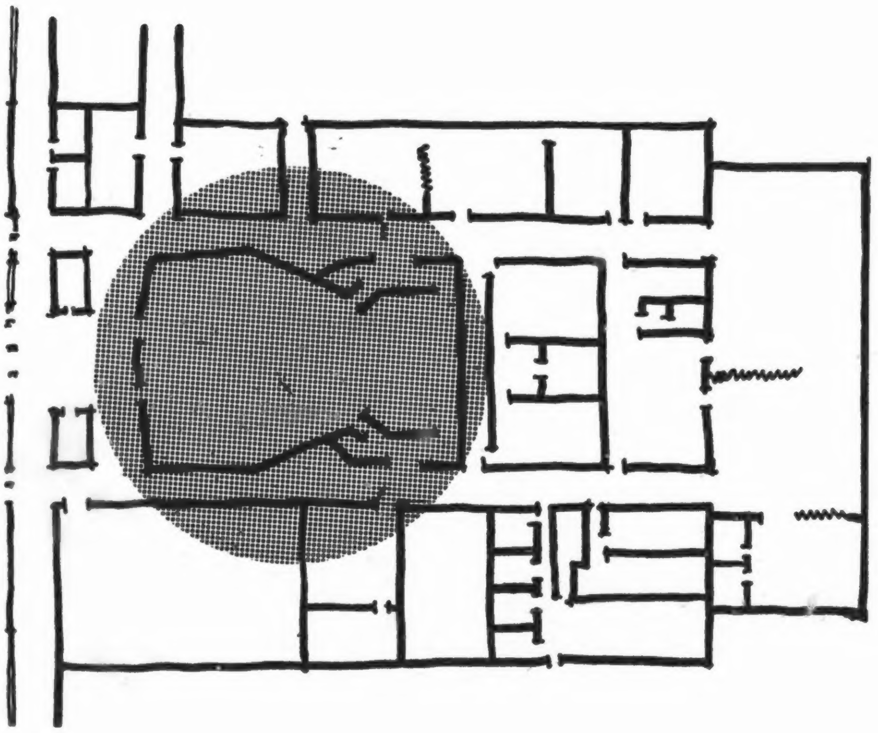


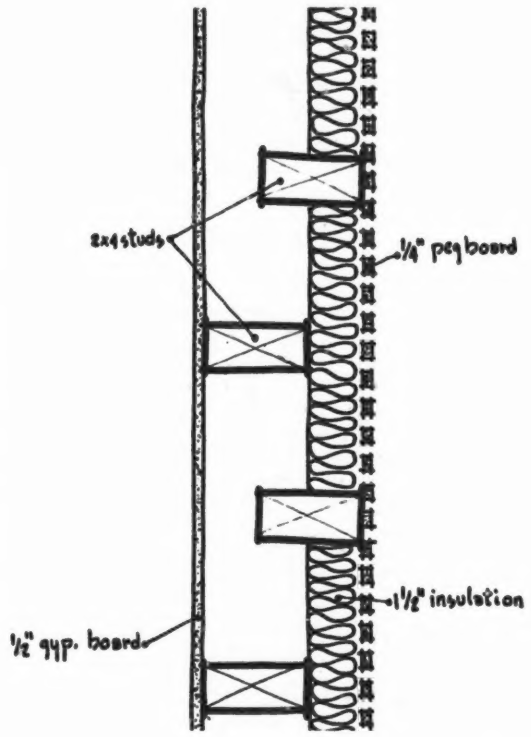
Reduction of the noise-transmission level may be accomplished by using land contouring and planting as a buffer or conceivably, steps may be taken to reduce the off-site noise at its source.

Of course, the existing noise level may be accepted initially with the realization that the later design of the building itself will have to reduce the noise problem. If this choice is made, architect and administrator must be quite certain that the later steps they intend to take - windowless design or special structural and finish treatments - will in fact reduce the noise level to tolerable proportions.

During site planning the building complex should be planned to minimize the transmission of unwanted on-site noises. Separation of noisy elements from quiet ones, use of changes in level of the site and contours, and placing underground noisy or quiet-demanding functions may be employed to meet these needs.

During building design the architect must continue to deal with on-site noise. In fact, some of his solutions, such as the separation of buildings depending on noise generation or requirements for quiet, are basically site-planning approaches to acoustical problems. The architect has a variety of plan types at his disposal ranging from blocks and single units at one extreme to clusters, campuses, and decentralized schemes at the other. These approaches can be used in an infinite number of ways to insure that each part of the building complex has the kind of sound and noise control it requires.





When designing individual rooms, the architect deals with two basic categories of wanted sound and unwanted noise. For rooms in which he seeks to provide particular acoustical quality, he may use room shape and volume or electronic means to achieve his goal. To deal with unwanted noise, he may avoid it by separating conflicting spaces or he may reduce noise transmission between its origin and the point of reception.

Next in the design process is the selection of materials and finishes. The architect who wishes to reinforce wanted sound can arrange reflective surfaces and materials to do so. To control unwanted noise, he may provide sound absorbing materials and finishes.

A number of important points arise from this brief outline of the planning process. Perhaps the most important is the observation that an acoustical problem, and the solution to it, can sometimes be deferred to later stages of design. This is, in effect, what happens when acoustical problems are unconsciously overlooked. However, one must be quite certain, in deferring solution to a subsequent design stage, that the range of options open to the architect at that stage is capable of providing a full solution; it may easily not be. Acoustical problems should be met at the earliest possible stage of design and deferred to later levels only when it is certain that a satisfactory degree of solution can be obtained. Far better to have rejected an undesirable site in the first place than to end up with an unworkable building.

A second and equally important point is that many of the acoustical requirements of a program should be met earlier in the design process. There will, of course, always be a need for the acoustical treatment of individual rooms; however, observation of existing buildings suggests that such "acoustical treatment" is too frequently used in an attempt to solve problems which could have been better solved earlier in design.

A third point is the observation that several different categories of sound origination must be considered: off-site, on-site, within the building, and within rooms. Each category, of course, has approaches most suitable to it. For example, acoustical tile on the ceiling of a classroom cannot help significantly in controlling noise originating from an adjacent playground.

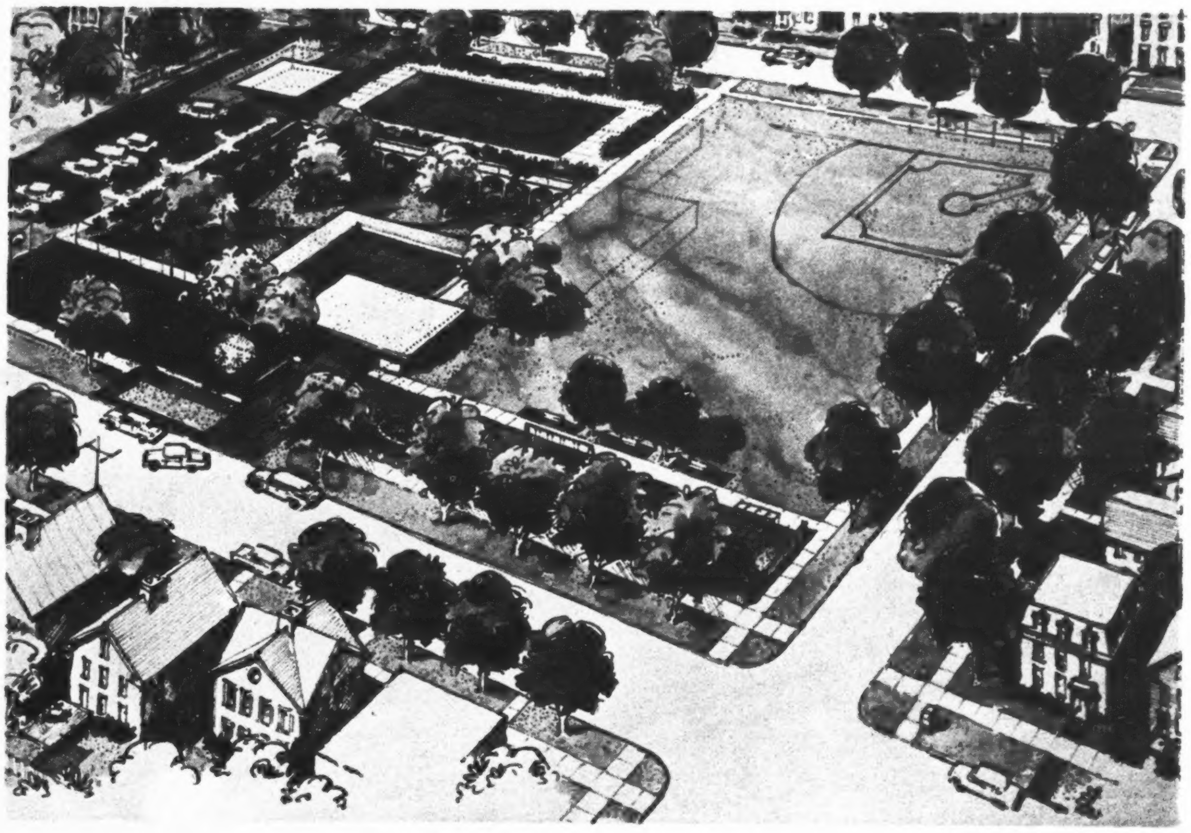
A fourth point is that both wanted sounds and unwanted noises are being considered; yet a treatment for one will effect the other. For instance, in an auditorium, the electronic magnification of a speaker's voice may also amplify the distortion reflected from a curved rear wall of the room. Finally there are a number of ways for the architect, in the planning process, to plan for wanted sound and unwanted noise. He can, as he does in auditoriums and concert halls, use the acoustical requirements as the basis for room shape, or, he can incorporate electronic aids to augment wanted sounds. In dealing with unwanted noise he can use space relationship, distance and level change, as well as the application of absorbent surface treatments.

One should not infer from this brief outline of the architect's potential courses of action that the "add-on" solutions to acoustical design problems are always inferior. However, observation of existing buildings provides evidence that "add-on" solutions are often used when earlier design solutions would have been superior. To this extent, then, there is a need for a better coordination of acoustical determinants at each stage of the design process.

• ACOUSTICS AND SITE

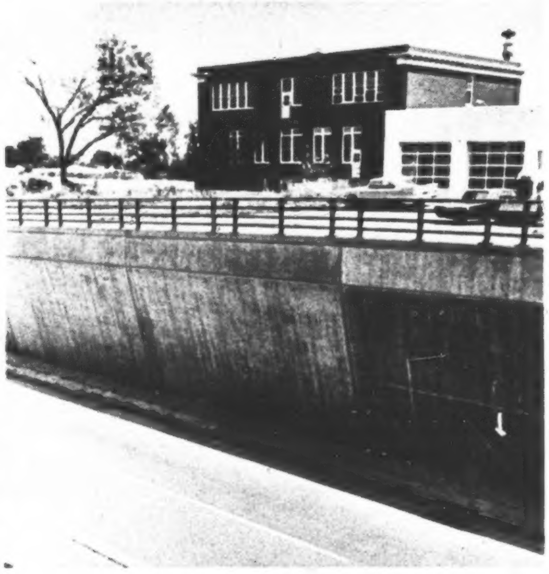
Many potential acoustical problems can be eliminated by thoughtful site selection, and other acoustical problems can be greatly reduced by the way the site is utilized and developed.

At the time the school board, with professional advice, purchasing the site, consideration should be given to avoiding nearby noise producing elements - highways, railroads, industrial complexes, airport approaches, and the like. Certainly this should also involve inspection of a master plan for the growth and development of the surrounding area as it might reveal projected roads, industrial complexes, airport developments, and other incompatible zoning which would render what may be initially a satisfactory site, an acoustically difficult site in the future.



Further in terms of site selection, size is important. If noise producing elements in the surrounding environment can be kept at "arms length" from the school building itself, by placing it on a large site, this should be considered. A wooded site, particularly one wooded at its perimeters, will help shield surrounding noise; terrain features, such as hills, rises, and man-made earthworks which raise topographical shields at the edge of the site, may also be considered.

Site selection for acoustics is extremely important. The quiet country school of today can be the noisy urban school of tomorrow, and an ill chosen site now may create major problems in acoustical planning and designing, and added building costs, tomorrow. Anticipation of future development patterns is the key to the solution of this problem.



Once a site has been selected and the planning process has begun, further acoustical considerations should be raised:

1. The building complex can be planned on the site so as to reduce the acoustical interference from surrounding elements, perhaps by placing part of the structure below grade or eliminating windows.

2. Landscaping can be planned to reduce traffic noise, and other disturbances.

3. Terrain features can be introduced to further reduce acoustical interference - earth taken in digging foundations can be used to mold a hill or rise as a barrier to external noise.

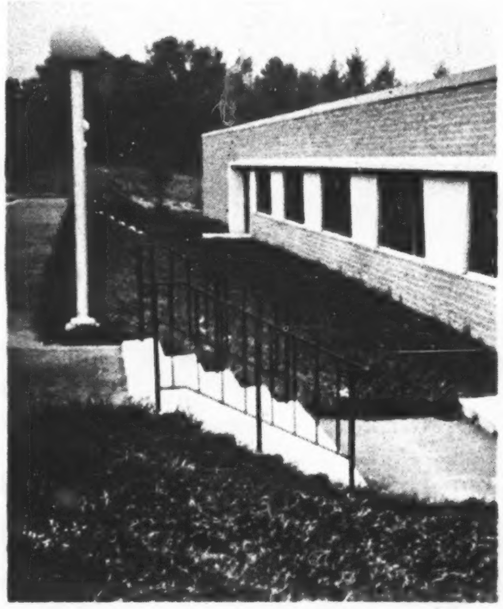
4. Parking lots, entrance roads, and school bus loading and unloading zones can be planned to be as remote as possible from classrooms, libraries, and other "quiet areas".

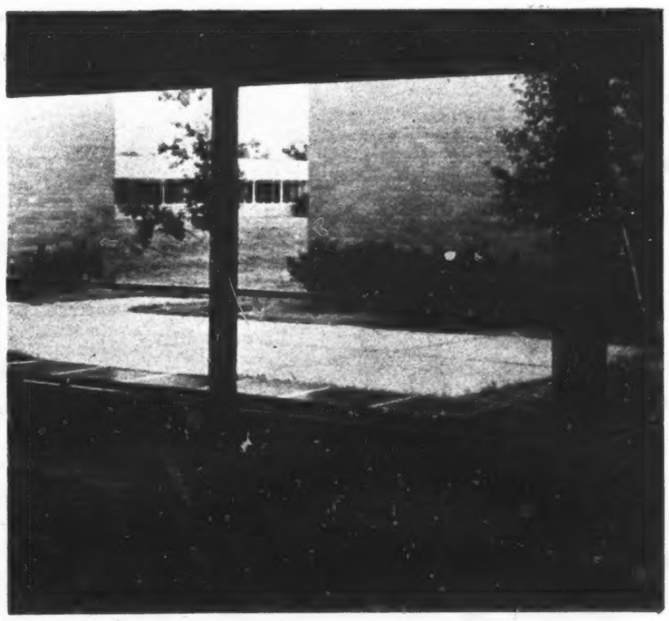
5. Playgrounds and athletic fields can be located in remote areas of the site or positioned so that acoustical barriers in the form of landscape, solid walls, or other building elements separate them from academic spaces.

6. Outdoor sitting areas, and circulation and "collecting areas" associated with auditoriums and cafeterias, can be located so as not to interfere with the quiet areas of the school.

7. Finally, the School Board can work with local planning agencies in developing a master plan which will insure that proper land use retains acoustically appropriate sites.

It is often impossible to define the point at which "site" considerations become "plan type" considerations, as one category merges imperceptibly into the other. Acoustical environment as affected by the school plan type is, therefore, a closely related concern.





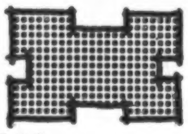
SCHOOL PLANNING

• ACOUSTICS AND PLAN TYPES

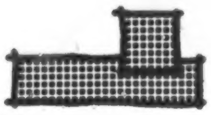
It is of value to consider the major types of school plans which are in use today, and to discuss each in the light of the strengths and weaknesses of the acoustical environment it provides. Obviously factors of function, health, safety, and construction economy would also be considered in a comprehensive review.

School building plans can be grouped into ten major types. Obviously, this number could be increased or decreased, depending on the importance ascribed to certain variations from types; however, the ten categories listed here cover the architectural range well enough to discuss acoustical implications.

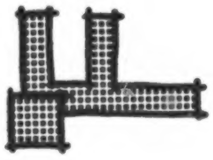
- Block Plan ....



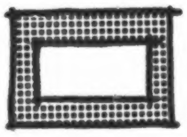
- Corridor Plan ....



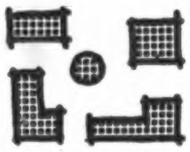
- Finger or Pavillion Plan .....



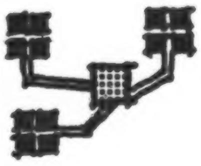
- Courtyard Plan ....



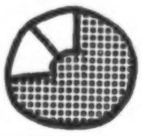
- Campus Plan ....



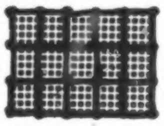
- Cluster Plan ....



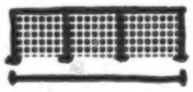
- Open Plan ....



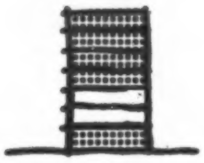
- Loft Plan ....



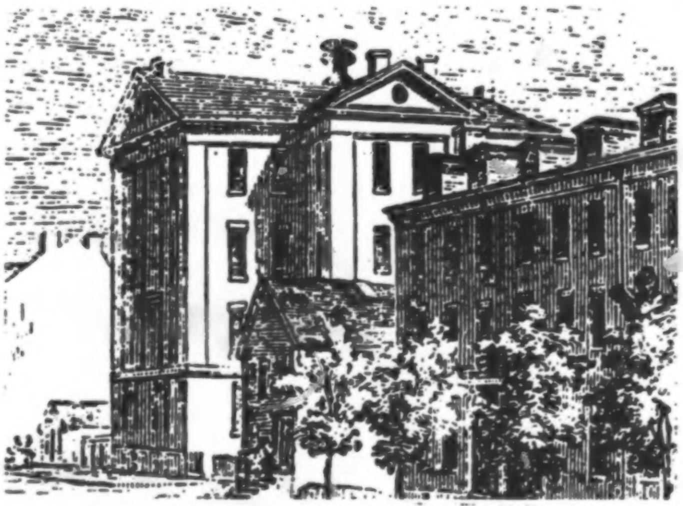
- Corridorless Plan ....

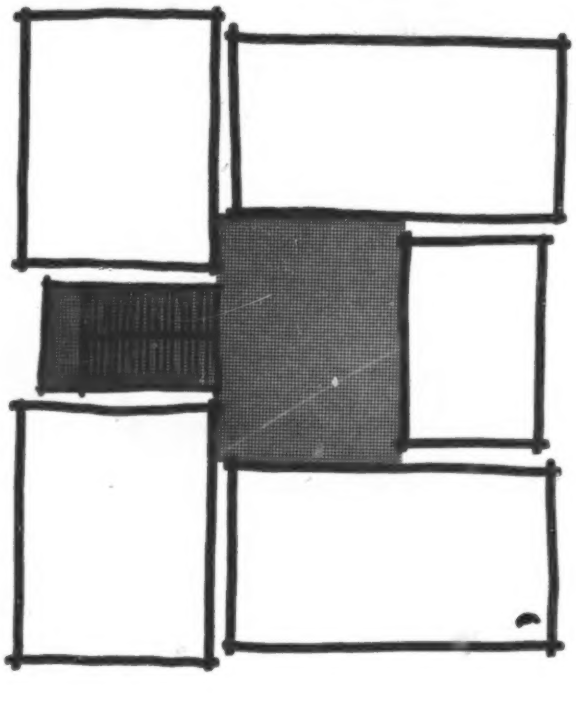


- Joint Occupancy Plan ......

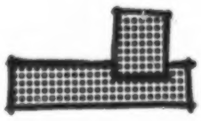


BLOCK PLAN



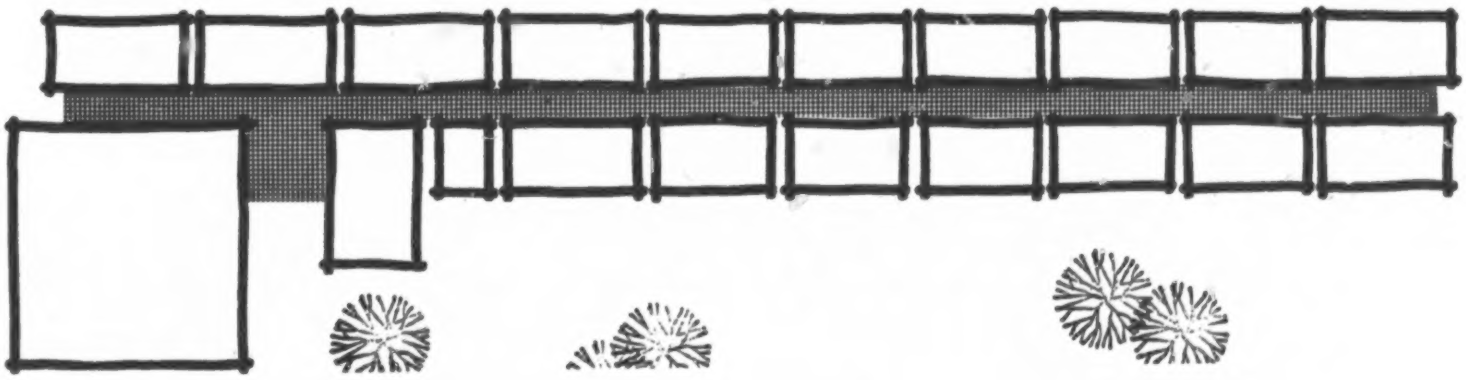


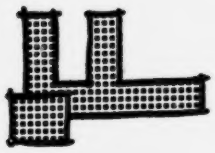
The oldest building type (and one that is presently receiving some new attention from architects and schoolmen) is the block plan. This plan may be traced to the 1847 graded school in Quincy, Massachusetts. It's plan provides 4 classrooms per floor, all rooms opening onto a central circulation area. A variation of this basic scheme consists of enlarging the central hall to the point where it can also serve some function, such as indoor play, assembly, special group work, and the like. The attractive aspect of this format is the high degree of "efficiency", in that there is a minimum of circulation space. The corridors' function is assumed by the central area, which can also be used as a teaching station. Acoustically, the absence of corridors reduces the amount of noise buffering between the perimeter classrooms and the central core area. For this plan to be satisfactory it is essential that the walls and doors between the rooms and the central space be capable of reducing noise transmission to acceptable levels.



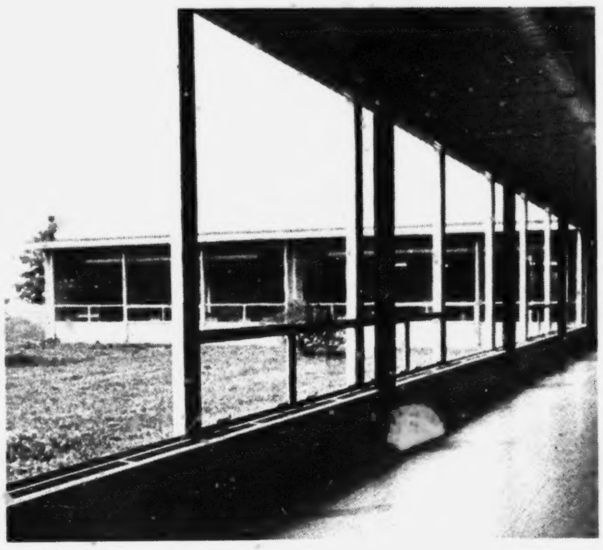
CORRIDOR PLAN

Next most traditional, and perhaps most commonly used in the heavy school-building periods of the 1930's through 1950's is the corridor plan. Also referred to as the eggcrate pattern, this design consists of classroom units ranged along one or both sides of a linear corridor. This building design has been found attractive because of its comparative simplicity, and its widespread acceptance by builders has resulted in closely competitive construction bidding. From the acoustical viewpoint too, the comparative isolation of each of the classrooms creates a good acoustical environment - provided, of course, that inter-classroom partitions form adequate enclosures and that corridors are not permitted to develop into noise-transmission tunnels.

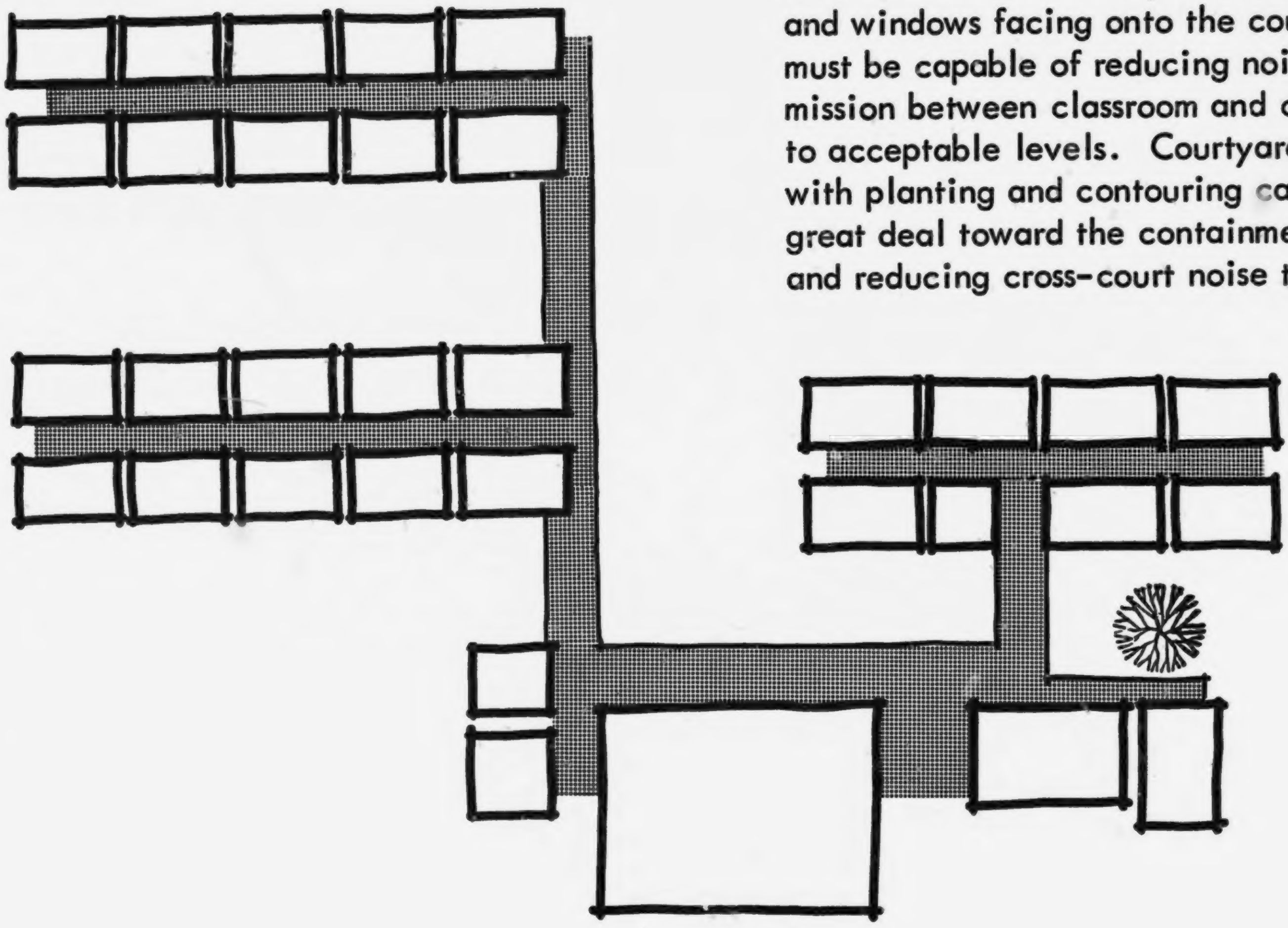




FINGER OR PAVILLION PLAN

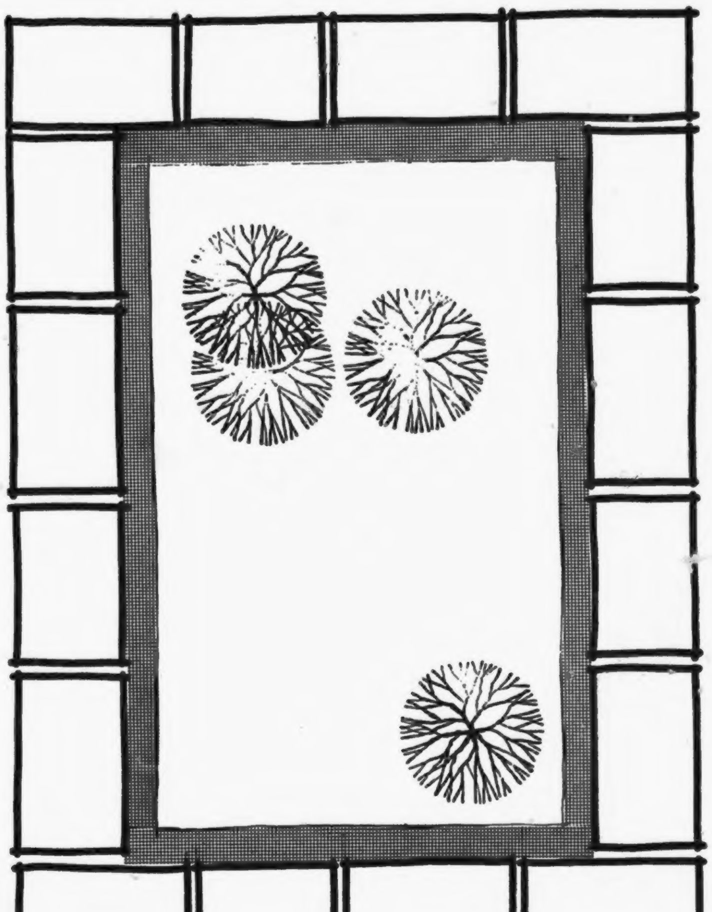


Closely related to the basic corridor plan is a refinement of it known as the finger or pavilion plan. Utilization of classrooms ranged along a corridor is the same, but the fact that rows of classrooms can face each other across a narrow courtyard has an additional set of acoustical implications. Cross-court noise, or noise of activities located in the courtyards, must be given consideration if this type of school design is to be used effectively. Classroom walls and windows facing onto the courtyard must be capable of reducing noise transmission between classroom and courtyard to acceptable levels. Courtyard design, with planting and contouring can do a great deal toward the containment of noise and reducing cross-court noise transfer.

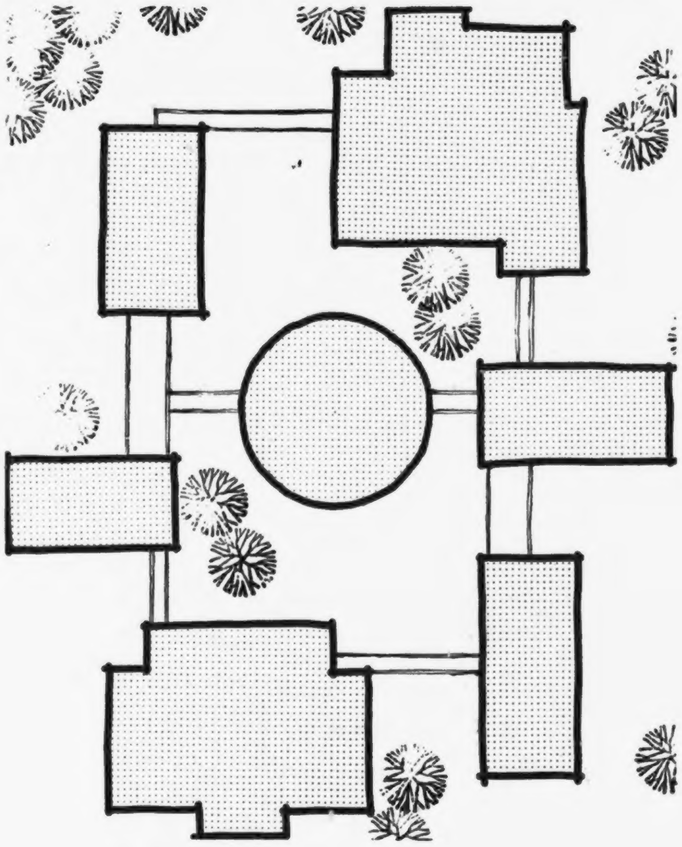


COURTYARD PLAN

Acoustical problems raised by the finger or pavilion plan are intensified when a courtyard design is employed. Cross-court noise may be contained by the enclosure of the courtyard and is not readily dispersed. For this reason more careful precautions must be taken. In many existing schools, inadequate acoustical planning of the courtyard has eliminated the possibility of the area's active use as a teaching area, and its function is limited to that of introducing air and light into an otherwise compact plan. In other designs, the courtyard performs not only the passive function of separating building elements, but also serves as the location for one or more teaching functions.

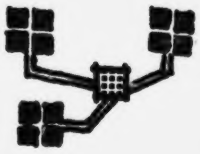


CAMPUS PLAN

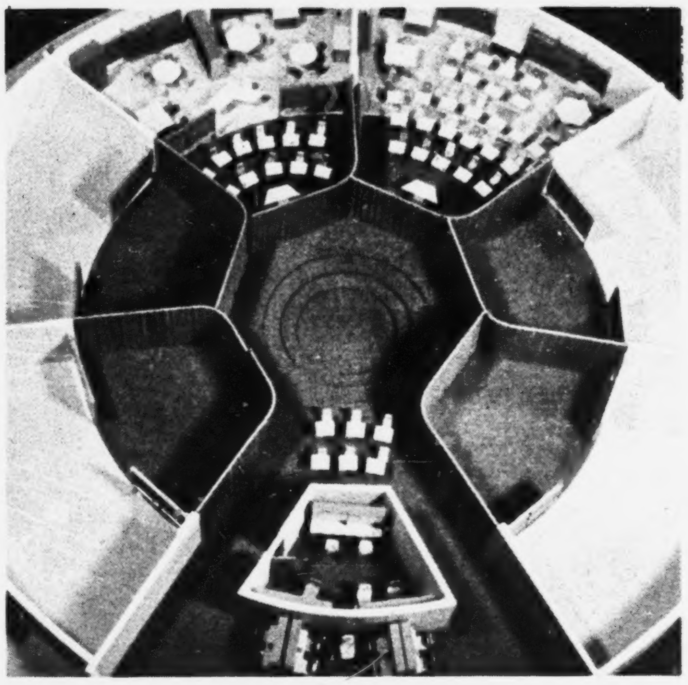


The campus plan differs from those so far described in that the plan elements are not physically connected to each other (except, perhaps, by an overhead shelter or similar type of linkage). Reduction of the overall building mass requirements to a series of independent components enables the architect to site his complex more freely and to adjust the relationships and distances between components; by putting a portion of the circulation pattern outside the buildings themselves, the "net efficiency" of the structures are also improved.

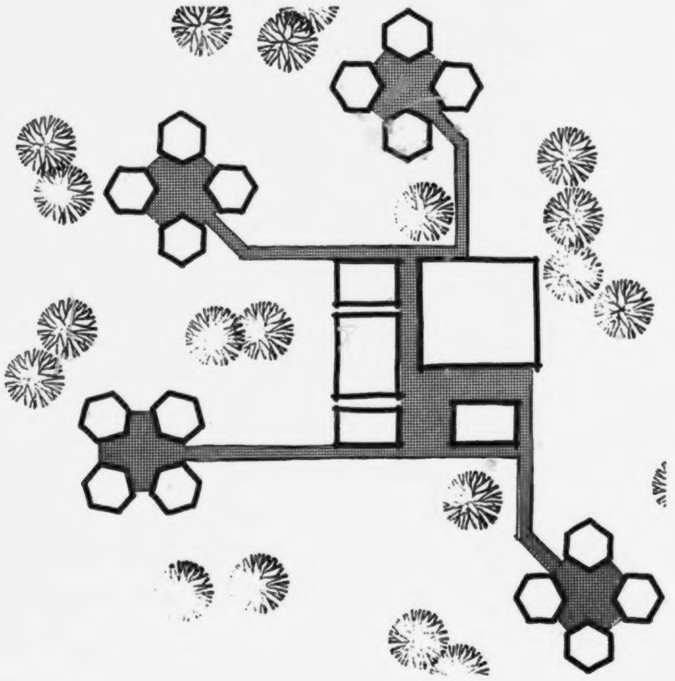
Within the individual components, of course, the acoustical problems to be met are no different from those in any block or corridor structure; but in dealing with inter-building relationships, the usually greater distances between components, the absence of structural connection, and the frequent existence of level changes and extensive landscaping all help to reduce the transmission of unwanted noise. In campus complex design, the same concerns of court and cross-court noise affecting adjacent buildings are present as were discussed for pavilion or courtyard structures, but the range of options for meeting these problems is greater.



CLUSTER PLAN



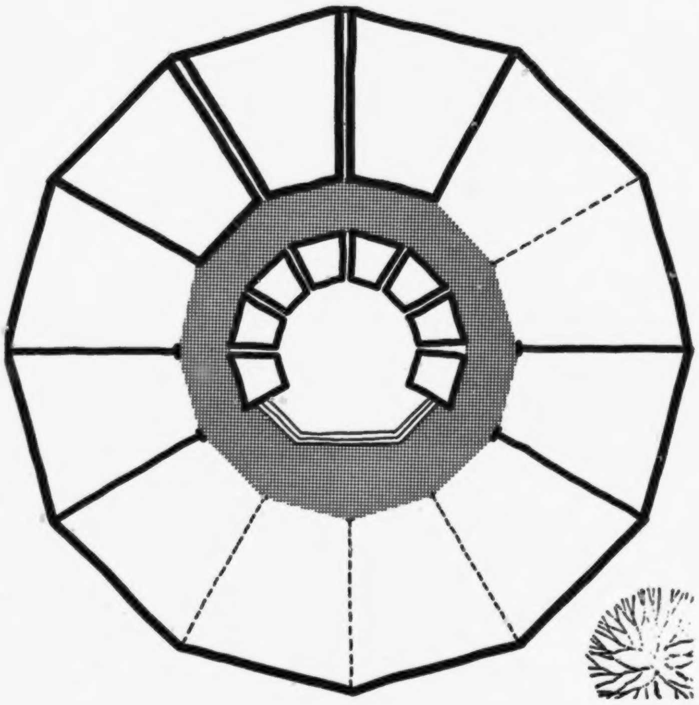
The cluster plan contains elements of both the loose campus-type designs and the tight block or corridor plans. Each individual cluster consists of a group of classrooms opening onto a central area. Each cluster, depends for certain services on a core facility in a central unit to which all the clusters are linked. This plan has proven attractive to schoolmen for a number of reasons, chief among which are the flexibility of use of the individual clusters and the capability of the plan to accept additional clusters as demands increase.



For acoustical purposes, the cluster plan shares the problems and potentials of the block plan (to which each cluster may be compared) and the finger or campus plan (depending on the solidity of the links between each cluster and the central core.) In many areas, the flexibility of the individual cluster is achieved by means of moving partitions or by partitionless, open design. Each of these departures from the standard, fully-enclosed classroom has its inherent acoustical problems, but none of these is incapable of solution. The key to success in the cluster design is the careful determination of acceptable noise levels and determination that the spaces, when finished and occupied, will meet these requirements.

OPEN PLAN

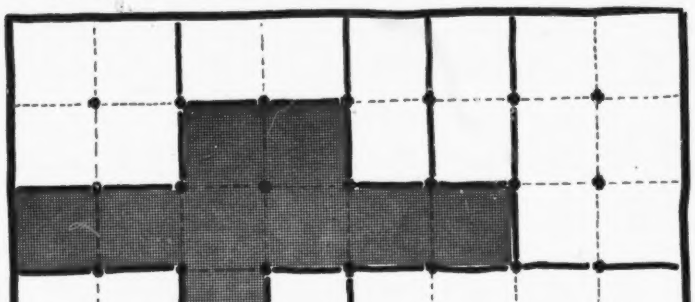
The open plan is attractive to educators for the same reason as the cluster design: its inherent flexibility gives administrators more leeway in adjusting to unforeseen program or enrollment requirements. Of equal importance, it gives them the opportunity to recast their building, virtually at will, to meet the requirements of a planned program sequence. Acoustically the plan hinges on the effectiveness of interior partitions (fixed and movable), finishes, furnishings, and inter-group distances to insure that pupils and teachers can function efficiently. Interestingly, building-to-building transmission of noise, often found to be a problem with campus or courtyard plans, assumes less importance with open planning. The reason for this probably lies in the fact that internal acoustical requirements in the open design are more stringent, and thereby tend to keep noise levels low. Also the student's adaptation to conditions of surrounding activity may make them less sensitive to outside noise sources.

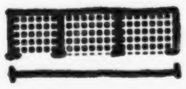


LOFT PLAN

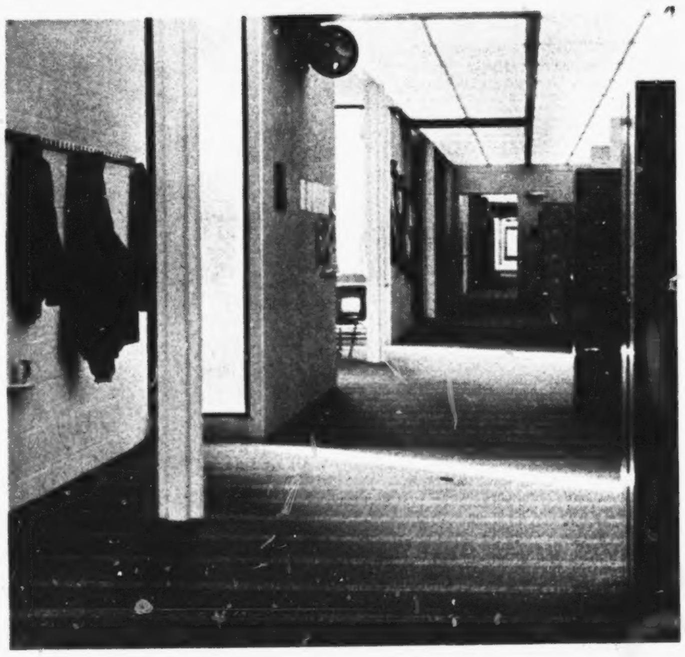
A further development of the open plan is the loft plan. This scheme consists of an envelope of sheltering structure in which the maximum number of partitions can readily be relocated to suit the requirements of enrollment and program. The loft plan is one of the more compact variations of architectural design in use in today's schools; its compactness is highly valued because of initial construction cost as well as subsequent expenses of maintenance and operation. This very compactness is a potential acoustical hazard, since both structure and air-borne noise can easily be transmitted from one space to another. However, the technology and manufacture of partition systems, such as would be used in a loft plan school, has progressed to the point where most established manufacturers are prepared to install systems with adequate noise reduction efficiency.

It should be pointed out that most contemporary buildings are designed with hung ceilings that have a space between the hung surface and the underside of the level above. Partitions which do not extend above the level of the hung ceiling to the structural slab cannot be depended upon to prevent room-to-room transmission of noise, since hung ceilings often do not possess satisfactory noise reduction capabilities. In the loft plan, the absence of permanent partitions means that there can be no slab-to-slab division of spaces: room partitions will simply fit between the finished floor and the hung ceiling. It is essential, therefore, in loft plan buildings, to circumvent the movement of sound through the plenum. This can be accomplished by specifying hung ceiling constructions with high noise-reduction capabilities; by absorbing an optimum amount of room sound in walls, floors, and furnishings; and by installing acoustical dividers between the hung ceiling and slab above each partition location. Full height partitions are very desirable, and special attention should be paid to the joint detailing at floor and ceiling connections, doors, and glazed openings, since these are points of weakness for noise leakage.

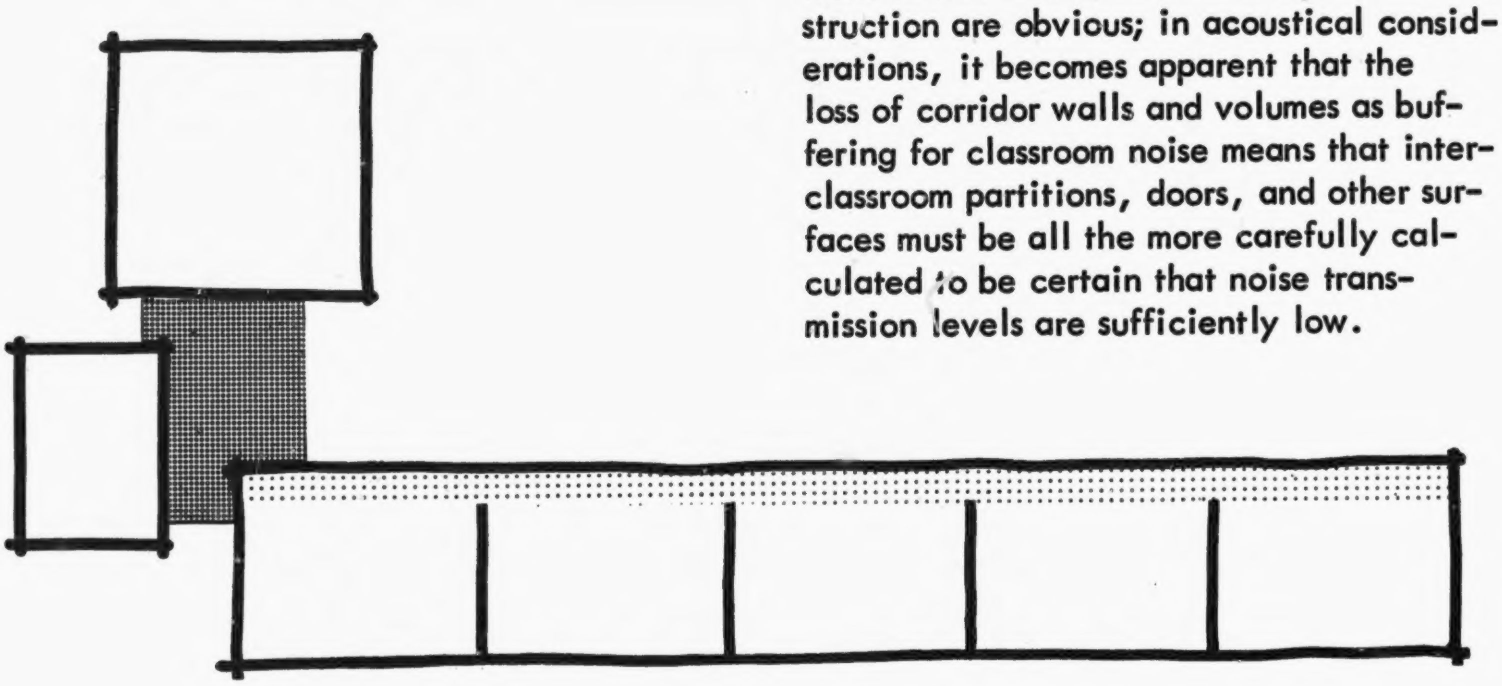




CORRIDORLESS PLAN

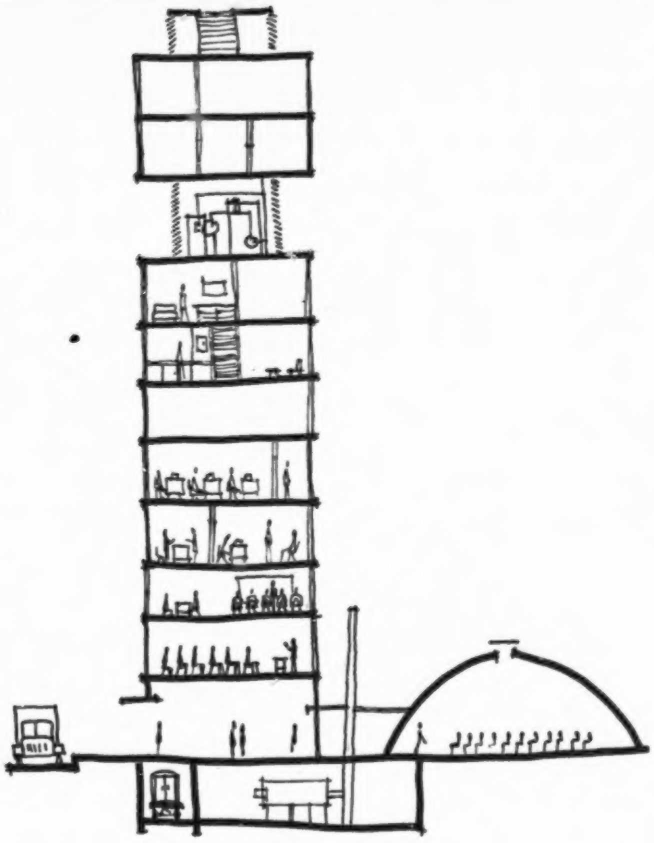


Corridor-less classroom wings are conceptually based on the educational practice of limiting the circulation of people in a school building to the periods between classes. Under this assumption, one sees that when corridors are in use, classrooms are not, and vice versa. Because of this, corridor noise cannot adversely influence classroom activity, and there is no problem of classroom noise adversely affecting corridor use (provided that further transmission to adjacent classrooms is prevented). Accordingly, the corridor-less scheme permits the use of one side of a classroom as the through circulation area, the area reverting to classroom use at the end of the passing period. The implications of this scheme for economy of construction are obvious; in acoustical considerations, it becomes apparent that the loss of corridor walls and volumes as buffering for classroom noise means that interclassroom partitions, doors, and other surfaces must be all the more carefully calculated to be certain that noise transmission levels are sufficiently low.



JOINT OCCUPANCY PLAN

A new type of design, appearing under the pressures of the shortage of space for school construction in urban areas, is the joint occupancy plan. Under this scheme, for example, a structure may be built on high-value land, or over a transportation right-of-way; in the former case, the school occupies a part of the building, the rest being rented out for income. In the latter case, purchase of air rights also has the effect of comparatively reducing site costs. The real acoustical problem with joint occupancy is the need for buffering between occupancies. Both air and structure-borne sounds need to be considered. The problem is further compounded by the typically higher ambient noise levels found in urban areas where this sort of site-sharing is most likely to be used.

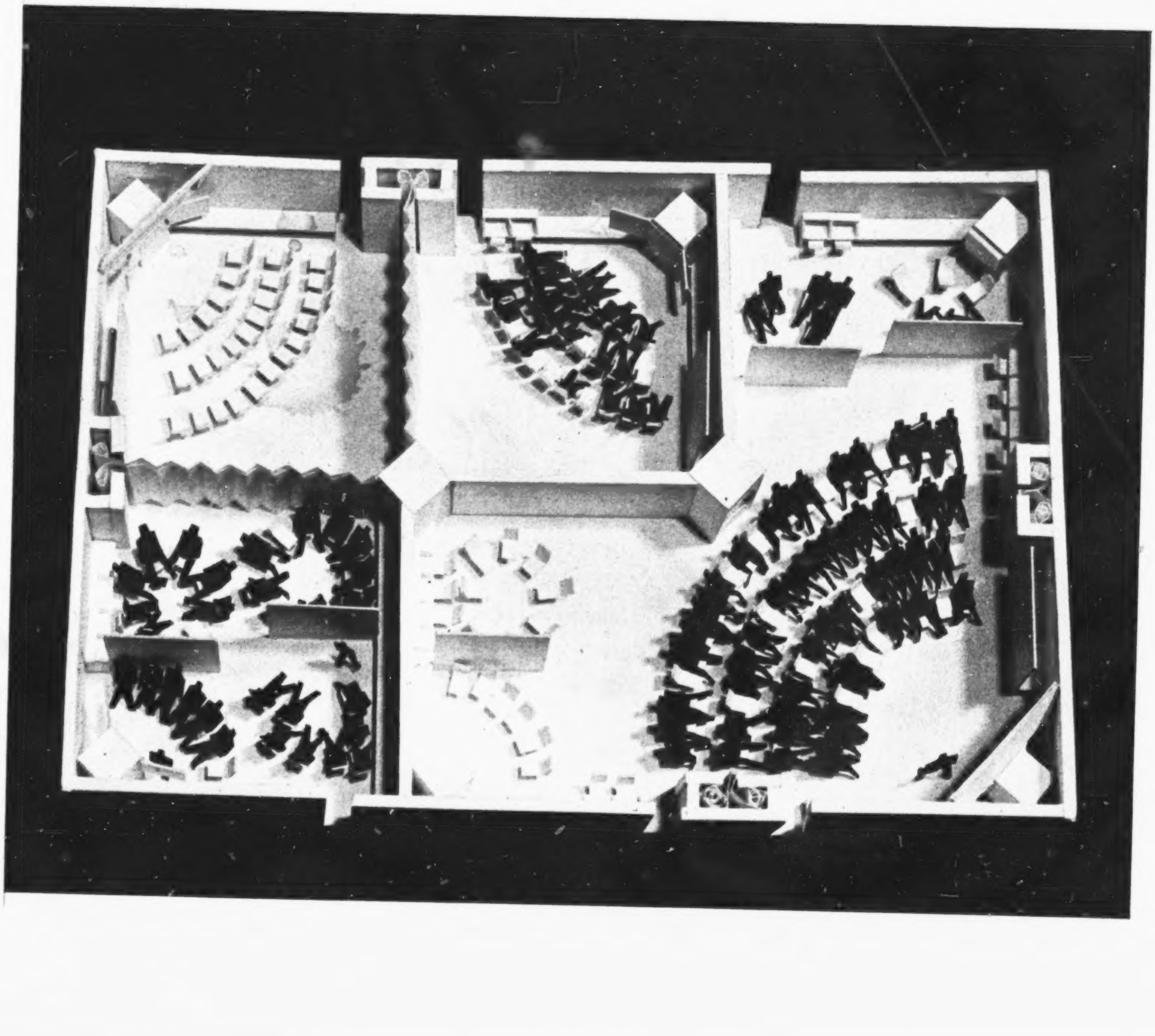


These plan types are not clear-cut; many variations and exceptions do exist. However, the discussion does emphasize the fact that the selection of a plan type inherently solves some acoustical problems, while raising others.

4

ACOUSTICS AND FACILITIES DESIGN

- ACOUSTICS WITHIN EDUCATIONAL SPACES
- DESIGN OF LARGE GROUP SPACES
- DESIGN OF SPACES FOR MUSIC
- DESIGN OF OTHER EDUCATIONAL FACILITIES
- FLEXIBILITY AND OPEN PLANNING
- SOUND SYSTEMS



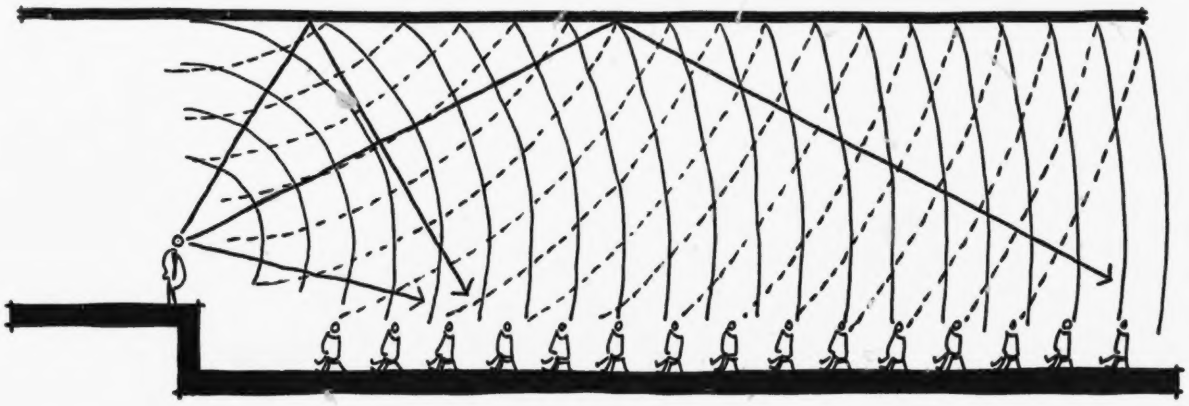
• ACOUSTICS WITHIN EDUCATIONAL SPACES

In its simplest terms acoustics in facilities design is concerned with two prime objectives; (l) the provision of a satisfactory acoustical environment by eliminating unwanted sound or by raising barriers to unwanted sounds originating outside the space and (2) providing good hearing conditions within a space by controlling the direction, impact and duration of sound waves.

In both cases, we have to consider the enclosing effect of the surrounding architecture. If the surfaces of an enclosure were wholly reflective - completely non-absorbent to sound - and if one were to neglect absorption due to the viscous nature of the conducting air, a single sound produced in this space would last forever. If one produced a series of sounds such as running speech, an auditor would hear only a meaningless jumble of the combined sounds. However, sound does not last forever; reverberating in the enclosure, it dies out, or decays.

This decay is the result of both the conversion of sound energy to heat, and its loss as sound energy transmitted through the barriers which enclose the space. The conversion into heat can occur by absorption in porous, sound-absorbing material, by the vibration of flexible, diaphragm-like surfaces, or by the loss of sound through the internal friction of the conducting air.

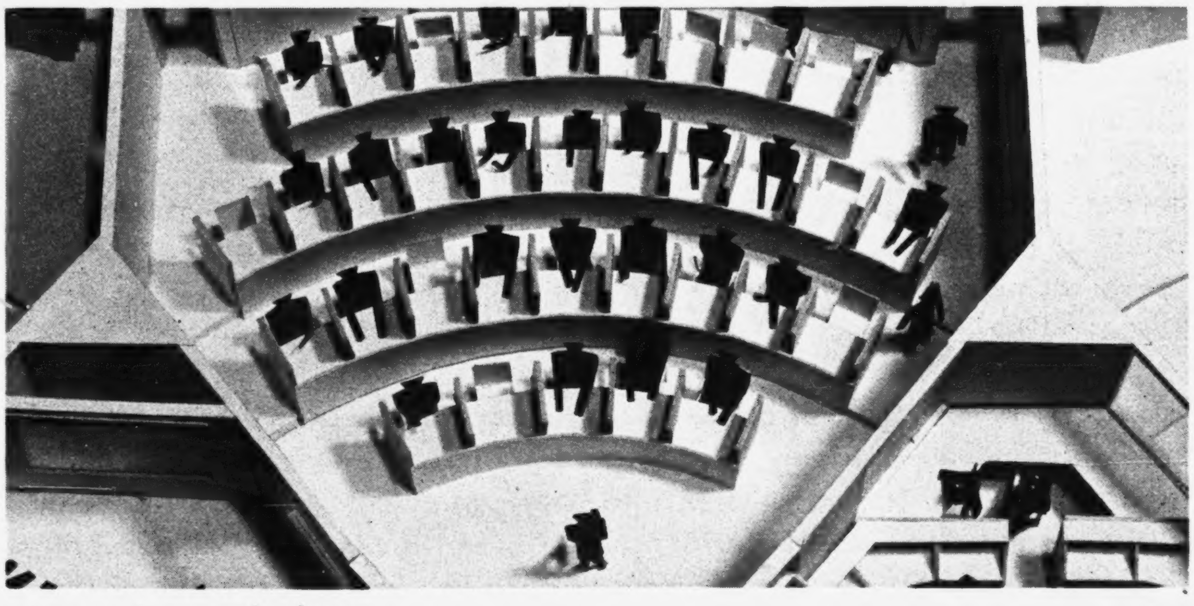
The advantageous characteristic of an enclosure is that it also reflects sound within the space. It contributes in this way to a greater sound intensity and richness.



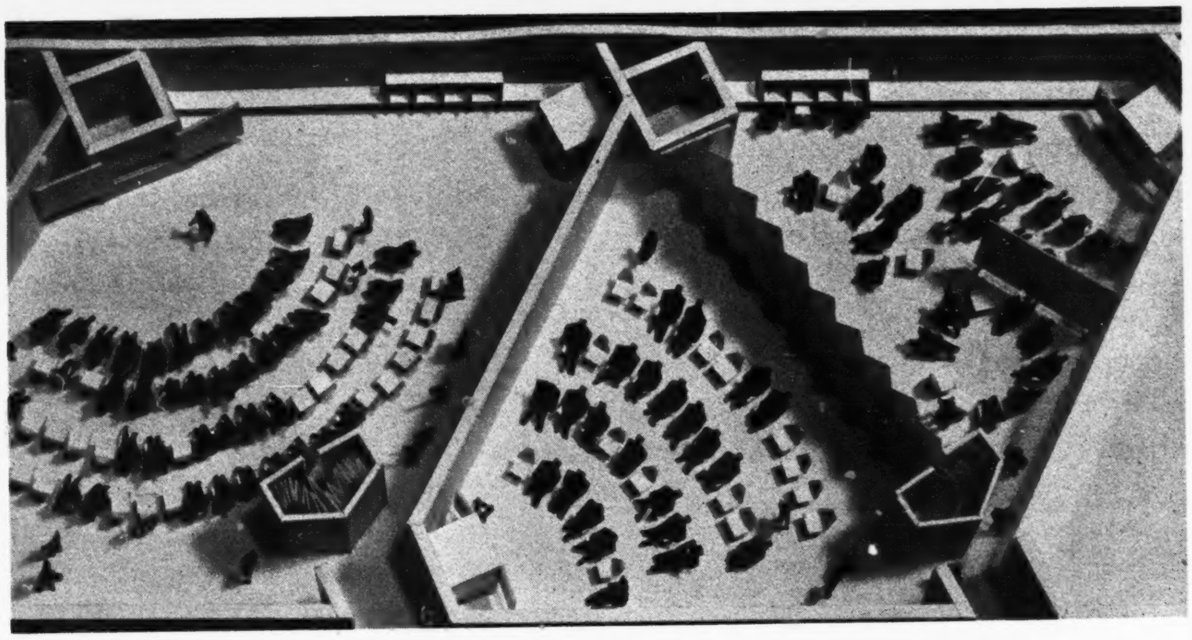
room enclosure reflects sound

Since the concern here is particularly with the absorption and reflection of sound waves within rooms themselves, room shape and the choice and judicious use of materials are key factors for the architect. The design of enclosures in terms of sound transmission is covered later.

The quality of hearing, for sounds originating within the room itself, is governed by the size and shape of the room, the location and volume of the sound, and the reflective characteristics of the materials in the room. Reflection, in turn, depends on the ability of these materials to absorb sound energy. A hard, dense material absorbs very little sound, reflecting nearly all of the sound waves striking it, while a soft, porous material acts oppositely, absorbing a large proportion and reflecting little.

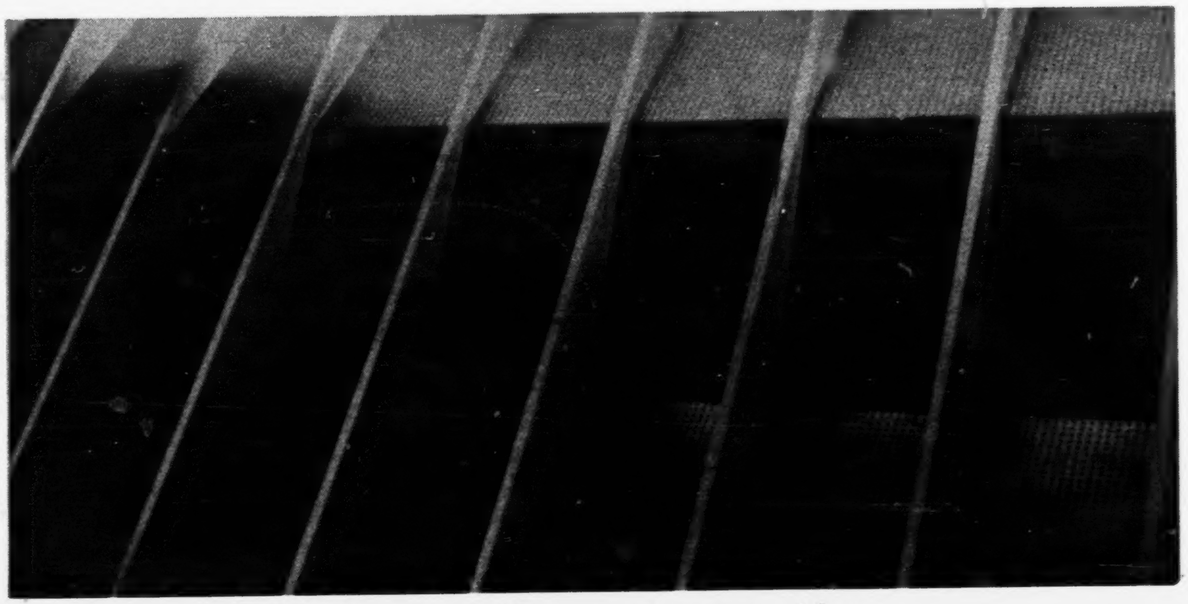


room size and shape ...



room furnishings ...

When large areas of porous materials such as carpet, upholstered furniture and special acoustical tiles and blankets are placed within a room the amount of reflected energy is greatly reduced, sound is largely absorbed and dies away quickly, and the reverberation period of the room is considered to be low. If, on the other hand, the surfaces lining the room are hard and therefore highly reflective, sound waves are bounced back and forth many times before they die out, and a long reverberation period results. This is the reverberant condition commonly experienced in empty and unfurnished rooms.

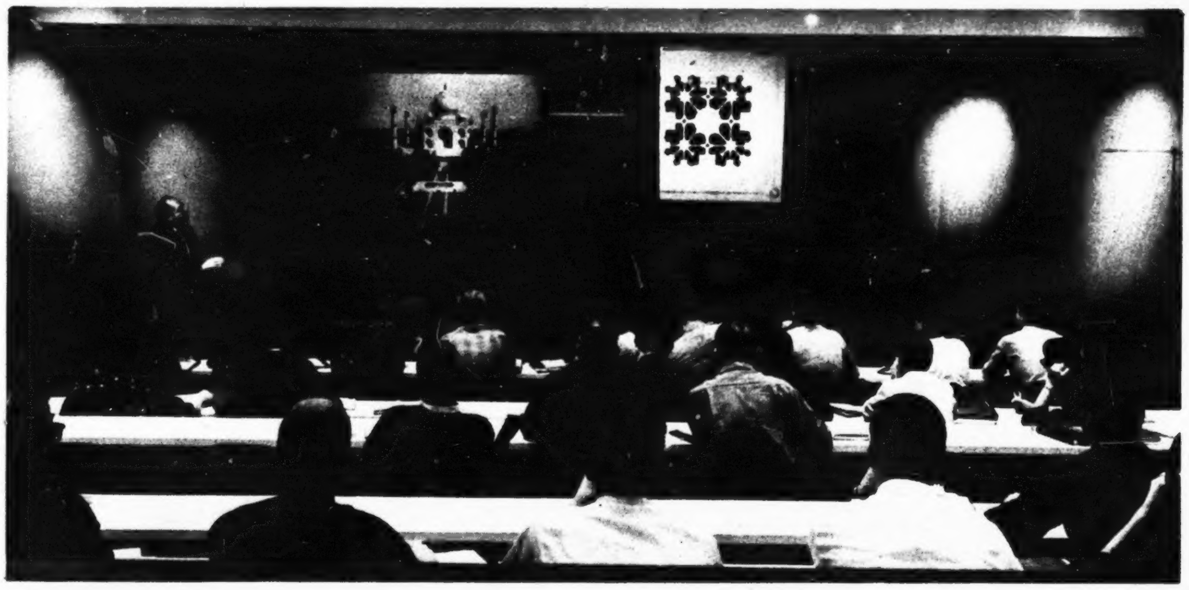


and room construction details govern acoustics

To obtain optimum acoustical conditions within each room, the design must respect these requirements, by adhering to the various yardsticks of design which have been developed.

• DESIGN OF LARGE GROUP SPACES

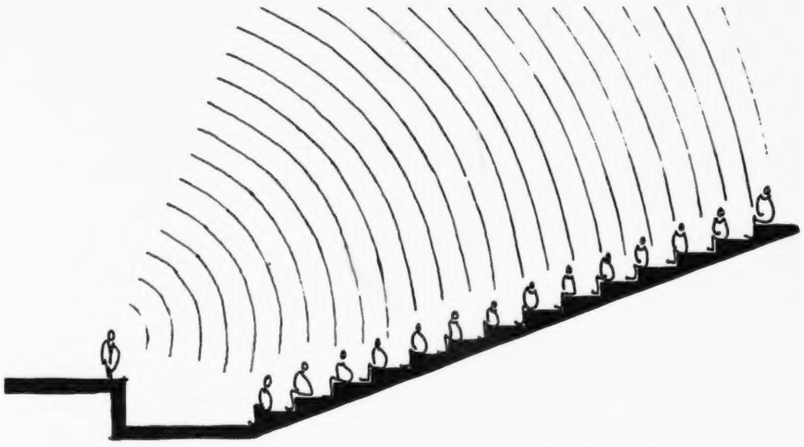
As a general rule, larger spaces require more careful attention to acoustical design in terms of shape and distribution of materials if optimum hearing conditions are to result. In other words, as room dimensions increase, reverberation, distribution, and volume are more likely to pose acoustical problems. Auditoriums, large group instructional rooms, little theaters, and other spaces designed specifically for an audience confronted by a speaker or speakers create a general category of space which have very critical acoustical problems.

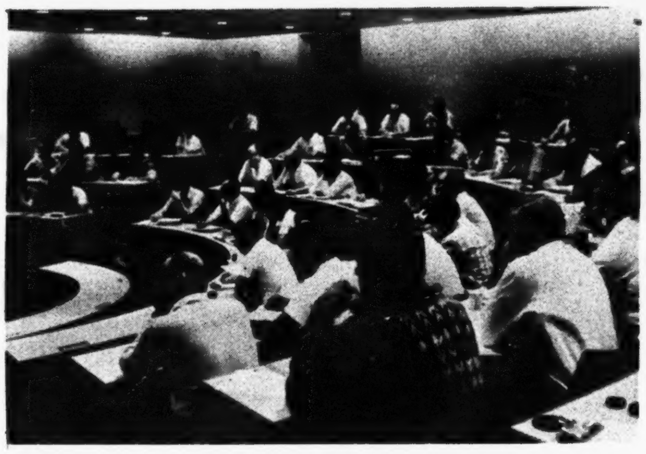


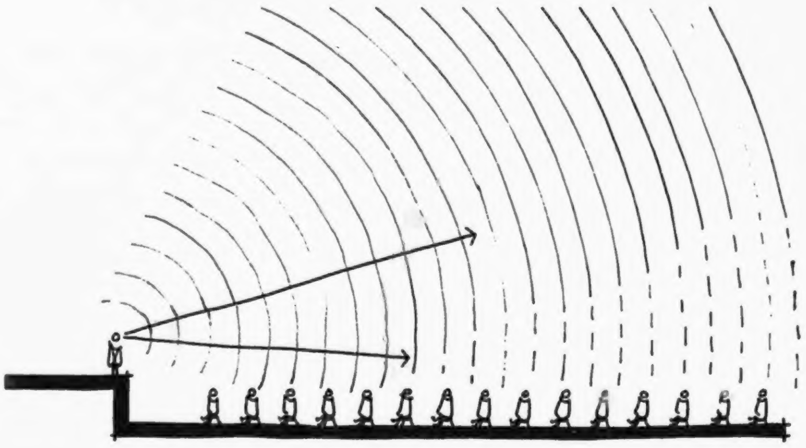
It is generally accepted that with proper design, an "unaided-voice auditorium" can be designed to hold up to 800 persons, and a room with some sound transmission assistance might be able to hold twice that number. Of course, an electronically equipped hall can practically be as large as necessary.

Architects who design schools will find their auditoriums used by speakers not as skilled as the professionals on whom the guidelines are based. Accordingly, maximum desirable capacities for "unaided-voice auditoriums" should be 300 persons in elementary school auditoriums and 500 in high schools. Schools which find it necessary to have larger auditoriums should not neglect provisions for reinforcement of voice and music.

In auditorium or lecture hall design, the dimensions of the space should also be considered. Experience shows that long narrow rooms are generally unsatisfactory; the recommended ratio of length to width ranges from 1.2:1.0 up to 2.0:1. Rear walls, of course, should not curve so as to focus reflected sound waves. Side walls may be splayed or otherwise treated to avoid flutter echoes and help distribute sound. A sloping floor is a distinct advantage in elevating successive rows of seats into the stream of sound; practical considerations govern the amount of slope - for acoustics, the greater the slope the better will be the effect. The entire floor need not be sloped; the higher the source of sound, the farther to the rear the level area can safely be extended. The relationship between height of sound and allowable level area can be expressed by the formula $d=r\ (2.5h-1)$. in which d is the distance to the rear of the flat floor, r is the spacing between seat rows, and h is the height of the sound source.



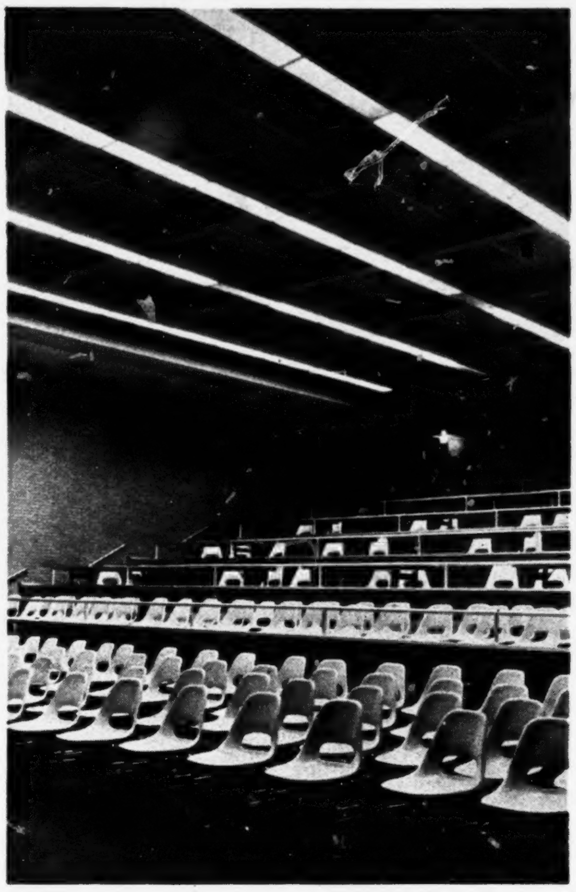


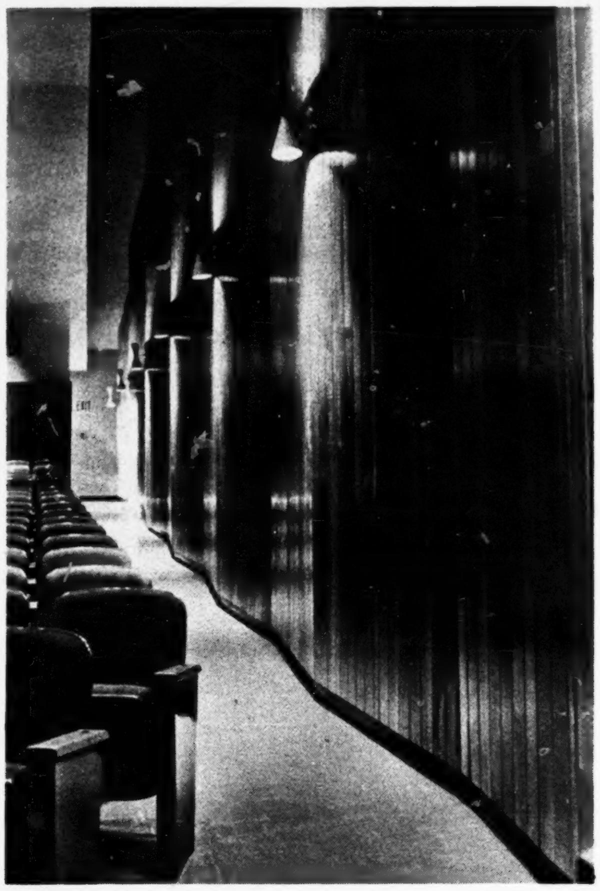


stepped seating improves hearing capabilities in large classrooms

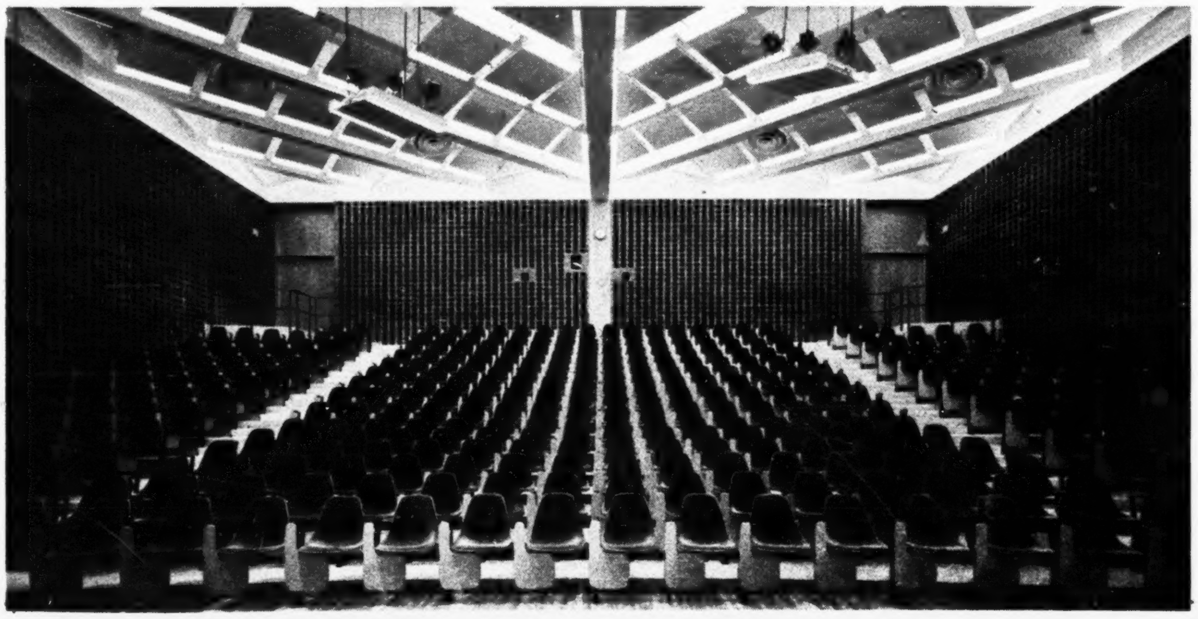
14

Because of the way their walls focus sound waves, circular and elliptical rooms should be avoided, unless some type of convex diffusing surface is to be used on the walls. To keep the audience as close as possible to the speaker and to the origin of the sound, and to maintain proper sight lines, non-parallel walls which focus on the stage are generally used.





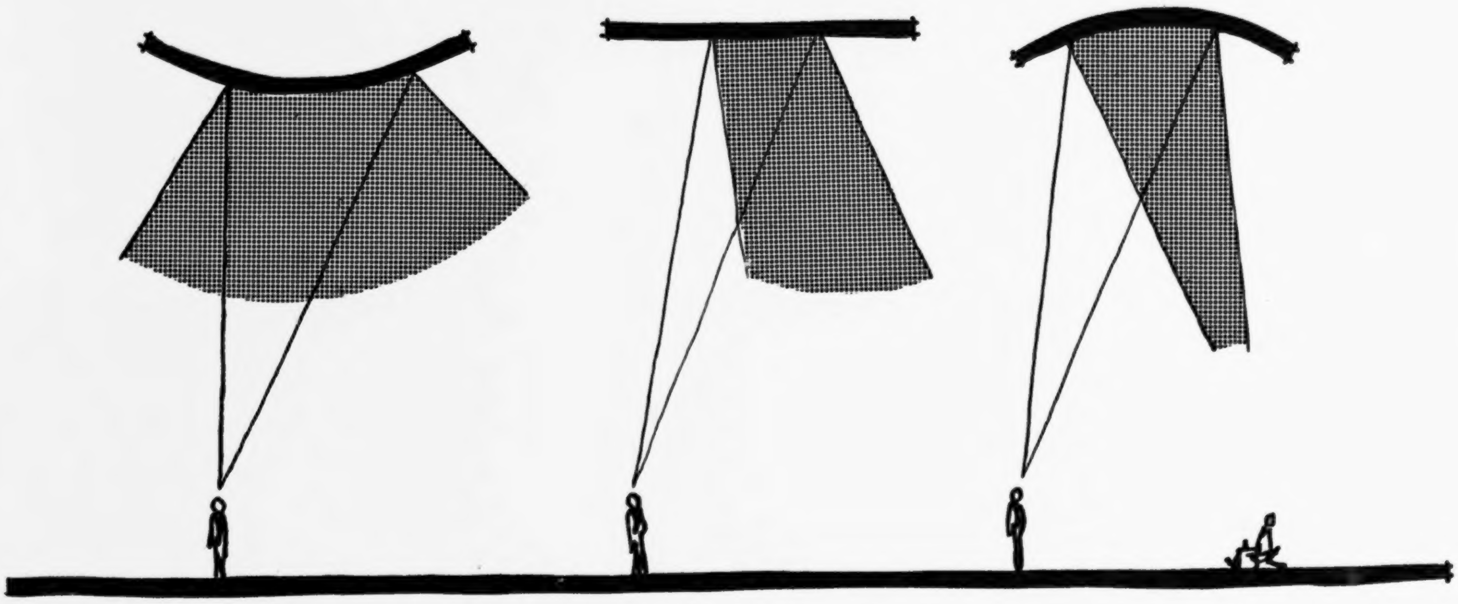
One of the avenues to good acoustical design is the choice of the proper reverberation time for the activity the room is to accomodate. Too short a reverberation time makes an acoustically "dead" room, in which it is difficult for speakers or performers to hear themselves, and to a listener it seems to "flatten" and weaken the sounds. Too long a reverberation time brings complaints of "boominess" and distorted sound transmission; the sustained reverberant sounds are especially harmful in blurring the successive speech sound.



Ceiling height is a critical component of room dimension. Optimum volume can be achieved, after the floor plan has established width and depth distances, by selection of the correct ceiling height. Most authorities recommend that the ceiling height of a room which is to be used for both speech and music be about one-third to two-thirds the width of the room. The proportionately lower ceiling height (approaching the one-third limit) is applicable for larger rooms; the proportionately higher ceiling is more desirable for small rooms.

The shape of ceilings or other surfaces should be such that the center of curvature of any concavity does not fail near the ear level of the room's occupants. A radius whose center is either below floor level or well above the listeners' heads will not re-focus or create sound echoes in a detrimental way. Nor should reflections from concave walls be permitted to re-focus near microphones or amplifiers; an oversight in this area can lead to feedback problems.

In these large rooms, the conformation and reflective quality of the ceiling are especially important. Provision, in effect, of an inclined "sounding board" surface over the speaker or stage area to reinforce and disperse the normal speaking voice is a basic essential, and in most cases, this can be provided by the conformation of the ceiling itself. The remainder of the ceiling may be treated as a series of large flat reflective planes offset in saw-tooth fashion by substantial absorptive breaks. Splayed side walls and a rear wall of highly absorptive material are characteristic of an acoustically good design for large spaces.

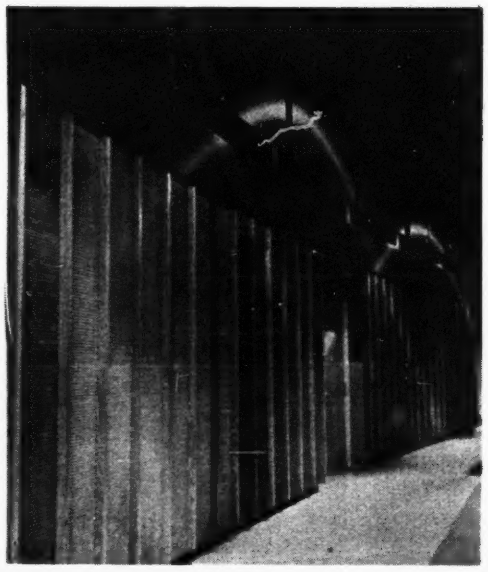


15

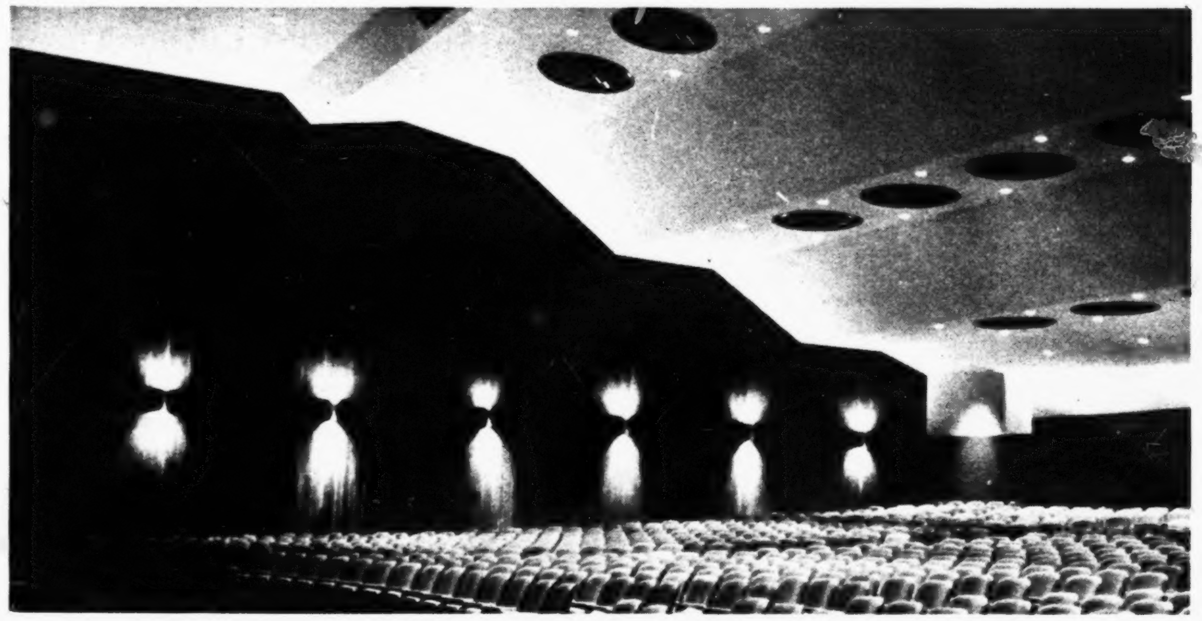
effect of surface shape on reflected sound

The acoustical objective in large rooms is to dispose reflective and absorptive materials within the room so that all occupants will receive as nearly as possible an agreeable volume of sound. In summary, for the designer this means that:

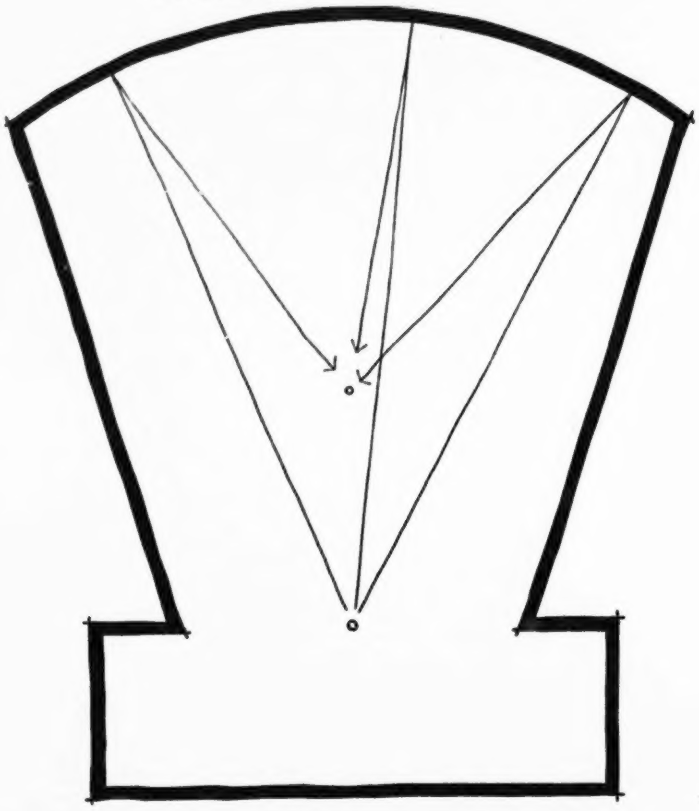
1. Surfaces relatively close to the sound source should be reflective to conserve and direct the original sound.
2. Surfaces behind the audience and facing the sound source should be absorptive to minimize a rebound of sound energy which causes delayed repetition of the first hearing.



3. Ceiling surfaces should be flat planes of hard reflective materials. Curved ceilings should be avoided because they focus rather than disperse the sound.

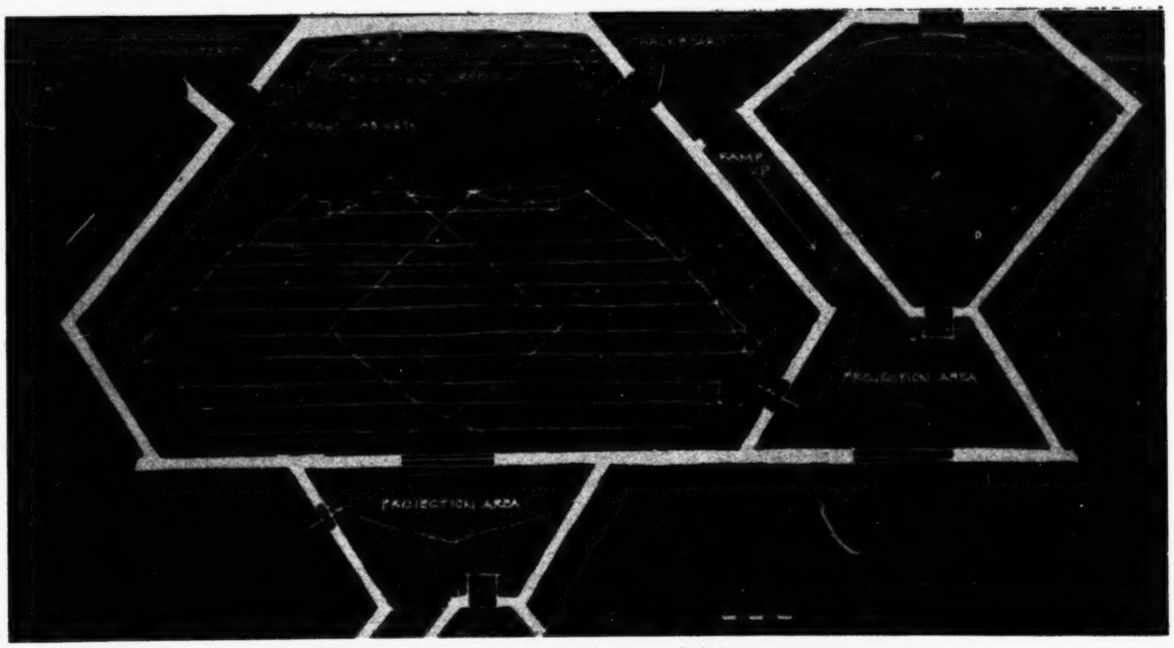


4. The rear wall, facing the speaker, should not be curved because it also tends to focus sound. If curved sections are used, the center of the radius should be well behind the sound source, or the rear wall should be broken up with large, convex diffusing sections.



curved rear walls, if not treated with absorptive materials, may focus sound

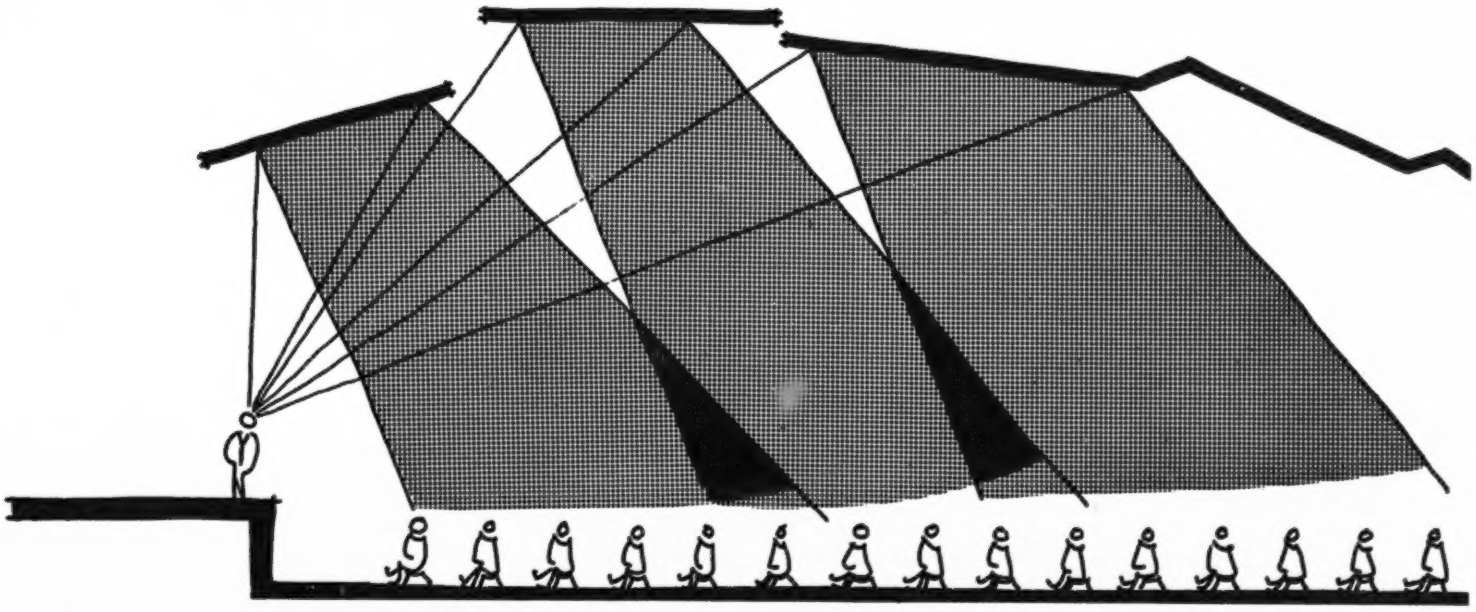
5. Non-parallel side walls diverging away from the sound source are sometimes preferable to parallel walls. This conforms to normal sight lines and can aid in directing sound.



16

non-parallel walls improve sound quality

6. Reflecting surfaces, whether on the walls or on the ceiling, should be comparatively large rather than small flat planes, and should have minimum widths of three to four feet; ten feet or more are preferable. Small surfaces only reflect sound waves of high frequency and short wave length causing distortion of the sound; larger surfaces will reflect sound waves of all common frequencies and wave lengths.



17

ceiling shape used to distribute sound

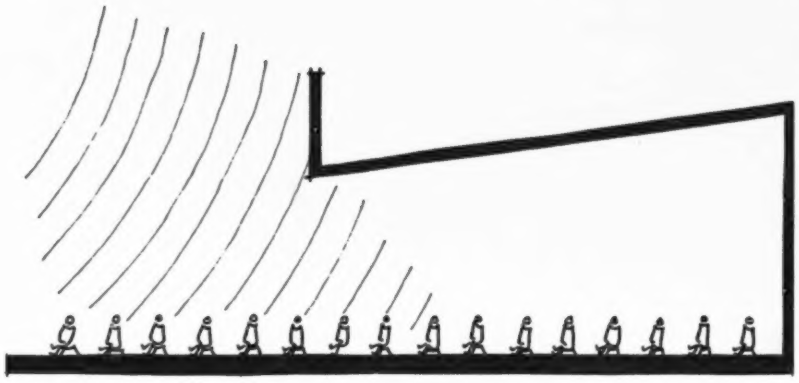
7. If a room is to be used frequently with only part of the seats filled, it will be desirable to include upholstered seats to maintain a desirable level of absorptivity in the absence of a capacity audience.

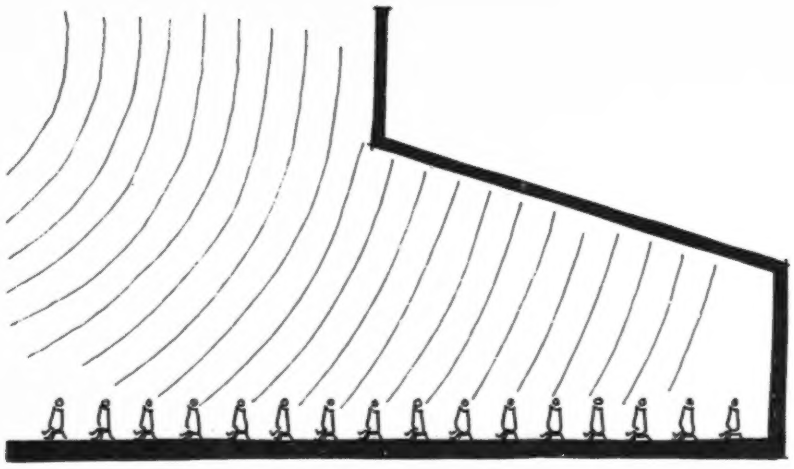
8. It becomes logical to use the acoustically better area for seating the audience, and the less efficient areas for circulation. Therefore, the area directly before the speaker is best for seating, with aisles located around the perimeter.

9. Carpeting can be used very successfully in aisles to control reverberation and reduce noise from walking.

10. If a stage is included which will be used for speakers, panel groups, or musical groups, a portable acoustical shell composed of hard reflective surfaces might be designed to aid in the distribution of sound from the stage area. In large rooms this is essential for unaided speech.

11. Balconies should be designed so as not to create acoustical "shadows" adversely affecting the rear seats of the orchestra level.





good and bad balcony design

18

The acoustical design of large group spaces in sometimes complicated by the fact that, in an attempt to build more economical schools by increasing the utilization of facilities, "multi-purpose" rooms are provided. "Cafetoriums", "gymatoriums", "gymaterias", and "auditerias" are part of a new generation of schoolrooms. They pose some unique acoustical problems.

It should be recognized that a room designed to support two such diverse functions as a cafeteria and an auditorium will never achieve wholly successful acoustical performance for either one. The acoustical criteria for an auditorium and a cafeteria are basically quite imcompatible and when a single space is designed to do both, no designer can achieve optimum acoustical results. The conflict may be minimized by:

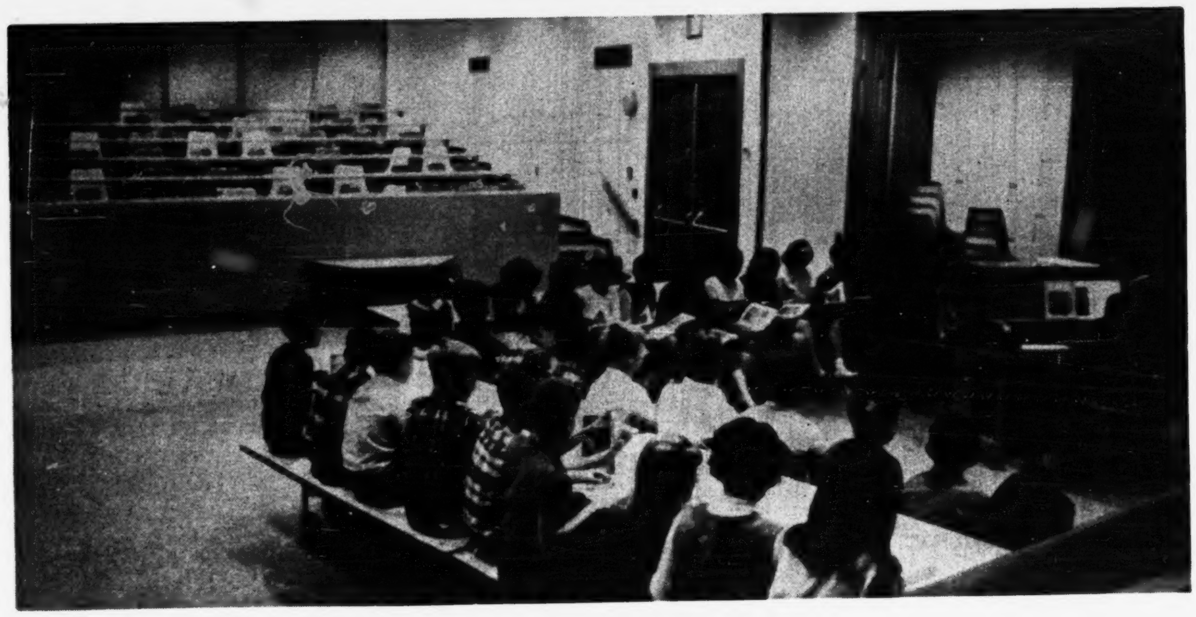
- building high sound absorbency into the room finish when the room is used as a cafeteria, and by relying on electronic means for sound distribution when it is used as an auditorium.

- using folding partitions which subdivide the space when used as a cafeteria but can be retracted for auditorium use.
- using furnishings with a high absorbency capability for the cafeteria function, removing or replacing them when the auditorium function is required.

• DESIGN OF SPACES FOR MUSIC

Spaces for musical activities, whether vocal or instrumental, pose a special set of problems in achieving good sound quality. One should consider that there is an elastic linkage, of which the room volume is a part, between the originating source and the mechanism of the listener's ear. For instance, the string of a violin produces a vibration which links itself to the sounding box and air volume of the violin itself. In turn, this is linked to the elastic volume of the room, and its vibrations then affect the ear drum of a listener. The wave form which reaches the ear drum, however, is never the wave form which is emitted by the initial source of the sound. There is in the linkage of elastic paths an alteration of frequencies caused by the characteristics of the chain of elastic bodies which tie the receptor of sounds to the origin.

These linkages and changes are often beneficial. The wooden body of a violin, rather than its strings, determines the quality of its sound, even though the origin of sound lies in the vibration of the strings. It is also important to understand that the elastic volume of the air in the room acts simply as an extension of the musical instrument itself, and that a room will have a distinctive character depending on its resonant characteristics and the selective nature of the absorption of sound by the materials of the room. The resonant characteristics are determined by shape and volume, and the present state of the art is such that these are not usually subject to analytical treatment. However, the absorptive characteristics of acoustical materials are well known, and it is possible to select surfacings and the arrangement of acoustical surfaces to distribute an evenly balanced reverberant sound to the listener.



FACILITIES DESIGN

The sophistication required for excellence in design for music, particularly for spaces for public performance, requires in most cases the services of a consultant in this field. A few general statements, however, may be of help.

There is a wide variation in types of music. A Brahms Symphony is intended to be performed by a large group in a large reverberant space. The nature of the music is such that its character requires fullness and the connection from one note to the other provided by the sustaining characteristic of reverberation.

A Bach Quartet is quite different. The volume is low, the passages are intricate, and the character of the music, and its charm, lie in the interweaving of various voices. A small room and a low reverberation time are essential.

Generally the somewhat lesser need to detect individual sounds of music, as compared with speech, leads to a somewhat longer reverberation time for all music. The variables in this, and in the most effective design for various kinds of sounds, tend to require more and more attention to possibilities of adjusting the acoustics of spaces to the varying needs. This is awkward and difficult because, acoustics being associated with the total volume, major changes in surface and shape are necessary. An architect must balance the needs for change with the complications and cost of changes.

Subjective response to music is variable, and performers are quite sensitive to the nature of spaces in which they are to perform. The acoustical qualities of spaces, as different from quantitative measurements, can be described in subjective terms. The following attributes of music and spaces for music are drawn from Acoustics in Architectural Design by Doelle:

- acoustical intimacy or presence - an auditorium has acoustical intimacy if music played in it gives the impression that it is being performed in an intimate, small room. The degree of acoustical intimacy in an auditorium will depend on the initial-time-delay gap, i.e., the time interval between direct sound received by a listener and the first reflection from any boundary surface of the room. Acoustical intimacy is probably the most outstanding acoustical feature that an auditorium, used primarily for music, can possess.

- liveness - an auditorium will be live if it has a large volume relative to its audience capacity, with predominant sound reflective enclosures. The live hall has a relatively long reverberation time, particularly at the middle and high frequencies, resulting in a full sustained tone at this frequency range.

- warmth - music has the quality of warmth when it has a fullness of the bass tone relative to that of the mid-frequency and high-frequency tones.

- loudness of direct sound - in a small auditorium, the audience, even when located in the remotest seats, will always receive an adequate amount of the direct sound. In large halls, however, the seats must be more steeply ramped, and the sound source must be well elevated, in order to provide a sufficient amount of direct sound for the remote seats.

- definition or clarity - if the sounds of the various musical instruments, playing simultaneously in an orchestra, are easily distinguished, and if every note within rapid passages is heard separately, the room possesses definition or clarity. Definition and fullness of tone are normally inversely related, i.e., a room possessing a high degree of definition will usually have a short reverberation time, and vice versa.

- brilliance - this will occur when there is an abundance of bright and clear high frequency sounds and will be more pronounced if the room has a considerable amount of reflective surfaces, liveness, and listeners close to the sound source.

- balance - the control of this attribute is partly in the hands of the conductor. Suitably proportioned reflective and diffusive surfaces around the sound source will strengthen and improve balance between sections of the orchestra, and between musicians and soloists.

- tonal quality - similar to a fine musical instrument, an auditorium can also have a beautiful tonal quality. Considerable damage can be inflicted on the tonal quality of a room by the creaking of doors, rattles caused by inadequately joined or fastened surfaces, or uneven or excessive absorption of sound.

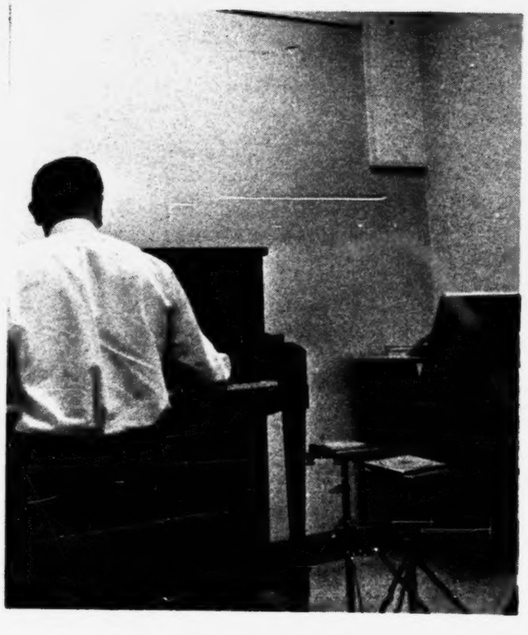
- uniformity-- uniformity of sound over the entire audience and performing area is one of the finest acoustical qualities an auditorium can possess. Listening conditions can be compara-

> tively poor at the extreme side seats of the front rows of a disproportionately wide hall, at locations receiving overly long-delayed reflections, and under an excessively deep balcony overhang. Absence of uniformity of sound can be particularly noticeable in very large auditoriums with an audience capacity of about 2500 or more.

Obviously the most critical problems exist in planning large spaces for music. However, there are other spaces to consider. One concern will be rooms for teaching musical theory, where the most careful attention by teachers and students needs to be given specifically and completely to the sounds being studied. Noise should be at a very low level and the character of the room should be such as to transmit sound with high fidelity.

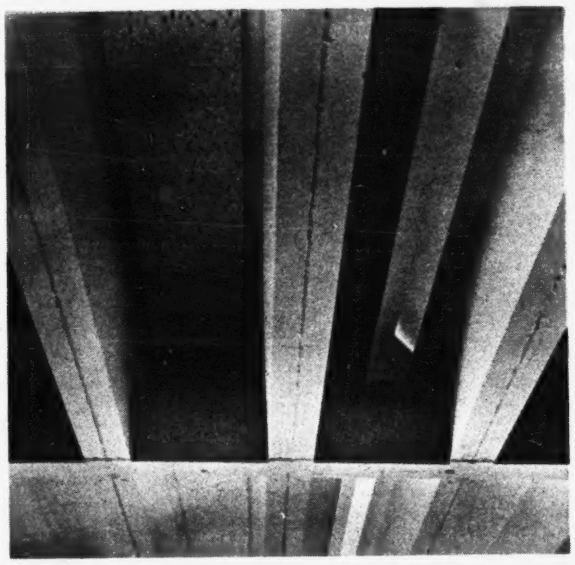
Other difficult spaces are rooms for individual practice, where undisturbed attention to the sound of the particular instrument is essential for profitable practice, and the isolation of noise to and from this room is a serious problem.

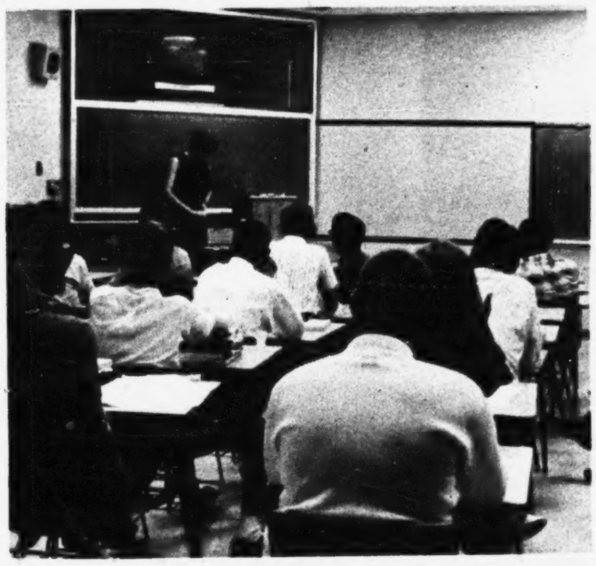
Finally, rehearsal rooms for large groups tend to be a noise problem mostly in terms of their effect on adjacent spaces. Also important is the arrangement of these rooms for effective rehearsal in terms of matching their characteristics to the actual room in which the public performance is to be held, and in terms of arranging the rooms of a shape such that each member of the group can hear clearly the sound from other parts of the ensemble.



• DESIGN OF OTHER EDUCATIONAL FACILITIES

In general, good hearing conditions are relatively easy to achieve in classrooms and seminar rooms. It will generally suffice to provide a peripheral area of absorptive material on all sides of the room except that occupied by the instructor. This may be either a border treatment, three or four feet in width on the ceiling, or if ceiling heights permit, a frieze treatment at the top of the walls. The central ceiling area is left hard and sound reflective, and wall surfaces in the area of the teacher or speaker should also be hard and reflective. The latter is inherent in the form of chalk board and writing surfaces. As the usual absorptive material is comparatively soft and susceptible to damage, the ceiling location is usually preferable unless the wall height is sufficient to install the material above head level.

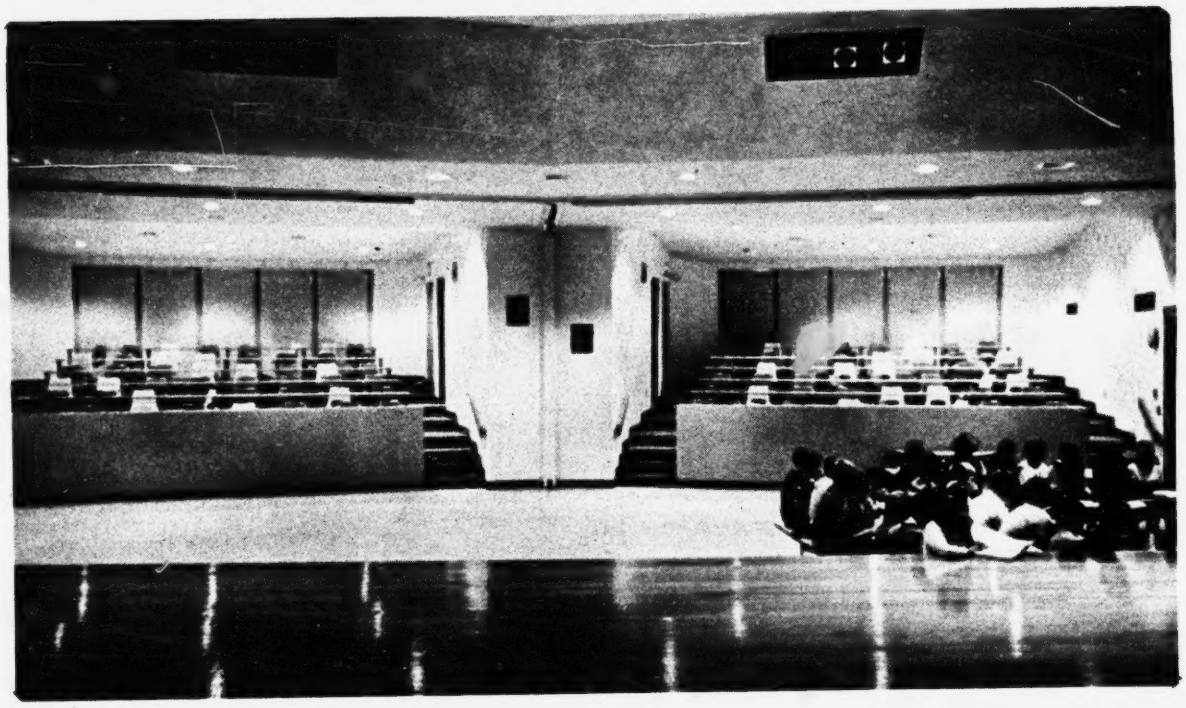




When recorded sound, either records, tapes, or films, is introduced in any of these general classroom or seminar rooms, the sound source, the loudspeaker, should be located in the same relative position as the classroom instructor. This will insure that the same factors of absorptive and reflective surfaces are put to work.

Some special purpose class rooms require acoustical design considerations. For instance, rooms containing typewriters and other business equipment should have substantially more absorptive material on the ceilings. This will help deaden the mechanical sounds of the equipment. However, this will render the room less satisfactory for the spoken word, as the highly reflective surface of the ceiling will no longer be available to reflect and distribute the teacher's voice. Science laboratories, home economics facilities, and arts and crafts facilities where the spoken word from a single instructor is not overly important, but where the noise of group activity and discussion will arise, should also have more absorptive materials. In any of these facilities where an especially noisy area or equipment is to be located, a panel of absorptive material can be suspended over the area and the surrounding walls can be surfaced with additional absorptive materials.

Somewhat larger special facilities include woodworking shops, metal working shops, and agricultural and technical training facilities. Generally, these spaces will have hard concrete or wood floors. More often than not, a shop classroom is part of the complex and the acoustical conflict between quiet and noisy activities may need consideration.



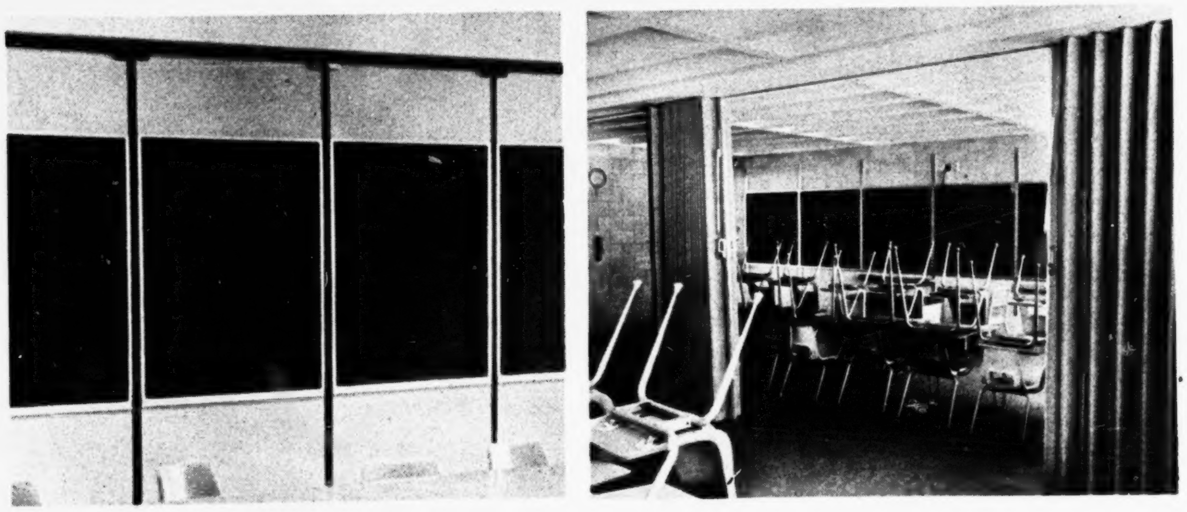
FACILITIES DESIGN

• FLEXIBILITY AND OPEN-PLANNING

Certainly there is no more commonly used, and often confused, word in education than "flexibility". In the broadest sense, it means the physical environment of education should be capable of change to accommodate variations in equipment, teaching methods, and groupings of students. It includes returning to the old ways as well as changing to accommodate the new; it may reflect indecision, or an inability to predict the kind of physical plant that will be required in the future.

Planning for flexibility has significant implications for acoustical planning. If one aspect of flexibility is to permit the rearrangement of space, then this requirement can be related to time; space can be rearranged on a period-to-period, day-to-day, term-to-term, or year-to-year basis. In the hour-to-hour or day-to-day approach, movable partitions are being used extensively. These partitions may be folding, rolling, overhead, sliding, accordion, and so on. They vary widely in terms of functions and may:

- provide tack or "write-on" surfaces and chalk holders
- operate mechanically, manually or electrically
- require both floor and ceiling tracks, and storage pockets



- provide perimeter seals and seals between sections
- require special structural support, or may be self-supporting
- permit re-location, or may be a permanent installation

- add to or detract from the aesthetic qualities of the space
- provide an ineffective or acceptable sound barrier

In meeting these varying functional needs, it is obvious cost will vary greatly - from $10 to $30 a square foot installed.

In terms of acoustical qualities, there is no single answer to flexible partitions. However, there are some basic principles which should be considered whenever flexible partitions are being planned:

1. Partitions with a decibel rating of 35 or more are available today. They are generally expensive. The decibel rating is a laboratory established rating; this does not mean that the partition, when installed, will necessarily give a 35 db difference in level. Room absorption is a factor, and construction detailing and the materials included in the walls, ceiling and floor surrounding the partition will have an effect.

2. Closure is important to acoustical separation. When a partition is in place, does it seal around the edges, and are there seals between each section of the partition? The smallest leaks between panels, or between the partition and the floor, wall, or ceiling, can be important in the degree of acoustical separation.

3. Construction detailing is likewise important. If the construction allows sound to be transmitted from room to room through the ceiling and above the partition, or at the ends of partitions around casework, windows, or other construction features, or if the detailing of the track or contact with the floor does not allow complete closure, then, again, an otherwise acceptable partition can be ineffective.

4. An important consideration is the type of operation. Some partitions can be easily manually operated by a lady teacher. On the other hand, the size of the partition required in a gymnasium or auditorium will require a crew to operate it manually or it will have a motorized operation. If the type of operation is not appropriate for the uses of the space on either side, the advantage of the partition may be lost. For instance, if a partition between two classrooms does not operate easily, it may not be opened or closed as often as it is educationally desirable to do so, or the partition may remain partly open all the time to allow for easier operation.

5. Long term maintenance and operation is another consideration. Several years after the installation of a partition will the gasketing still work, will the closure still close, will the writing surfaces still be useful, and will it still open and close as readily as when it was first installed?

6. Functions to be housed on either side of a flexible partition must be acoustically compatible. A recitation classroom and a library divided by a folding wall would not be sound planning. A room planned for extensive use of instructional media-films, tapes, records, and television should not be paired with a room where such sounds would be distractive.

7. Two relatively inexpensive, easily installed and operated partitions used to provide a double wall, may be more effective than the best single folding partition.

8. Practically any flexible partition will not perform as well, acoustically, as a block wall or double stud partition. The educational advantages of flexibility, such as teaming and teacher utilization, must outweigh the advantages of better acoustical isolation.

On the term-to-term or year-to-year kind of flexibility, one obvious answer is the "office-type" or demountable partition. One of the recent significant developments in "educational facilities planning" has been the development of relatively inexpensive, easily installed, and highly functional demountable partition systems. These partitions which require a maintenance crew to take them down and set them up again, allow for the rearrangement of space between terms or between the school year, or in some cases during a weekend or vacation period. Again some cautions should be considered:

1. The decibel ratings of demountable partitions are also laboratory established. If the structural details, if the installation, or if the closures in the actual installation allow acoustical leaks, the laboratory rating will not be achieved.

2. Construction details are again vitally important. An otherwise suitable partition may be rendered inefficient by the sound transmitted from one side of the partition to the other through ceiling panels, adjacent partitions, openings, casework and other construction details that have not been given sufficient acoustical consideration.

3. Compatible functions, in terms of acoustics, should be paired or grouped in planning.

There is another type of flexibility that has been used for years - the simple, non-load bearing partition. These partitions, which may be torn down and or laid up quite quickly and inexpensively, offer a degree of flexibility which can allow a school plant to adapt to changing needs over a long term basis. Concrete block, brick, wood frame, and lath and plaster partitions may all be of this non-load bearing, flexible type. Generally, they offer better acoustical privacy than may otherwise be achieved by "flexible partitions", but such an approach to flexibility should be considered only for long term solutions. In terms of cost, a painted concrete block wall will cost about $1.25 per square foot in place, as compared to $2.00 to $3.00 for the demountable partitions mentioned previously.

"Flexible planning" or "open-planning" are responses to the educational need for rearranging and regrouping students, teachers and learning resources. They are a reaction to the rigidly graded and organized "egg-crate school"; they are an attempt to house team-teaching, team-planning, non-gradedness, individual tracking, and many other innovations in current education. Acoustically they raise questions such as:

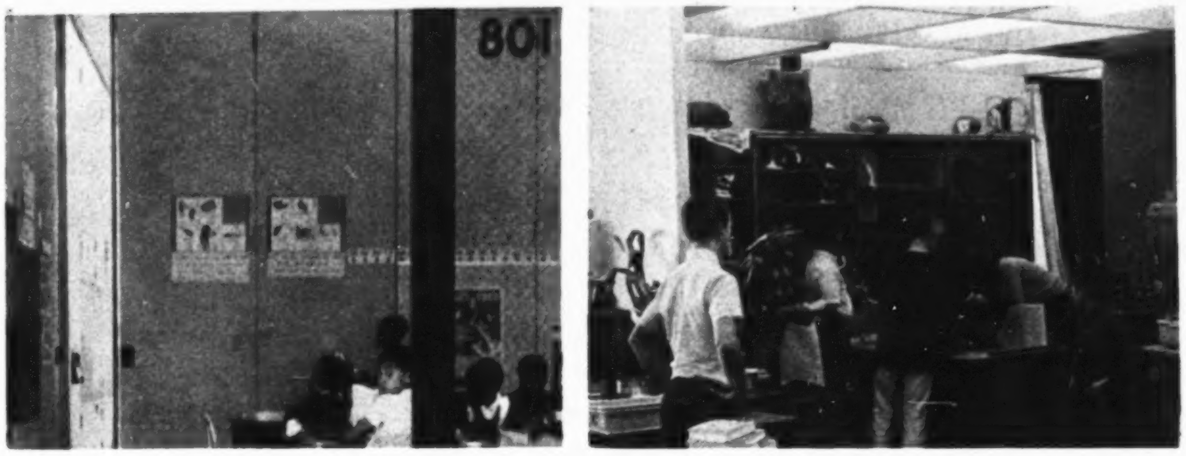
- Is acoustical isolation a necessity for all educational activities?

- Does the freedom to allow movement, regrouping, and cooperative teaching override a need for acoustical separation?

- When people gather in a restaurant, intimate and significant conversation can take place around the table without acoustical isolation; can such principles apply in some educational settings?

Across the country there are very significant school buildings which are working examples of open-planning; these "corridorless" or "doorless" plans, often with intervening "flexible partitions" pose some unique acoustical considerations:

- Teachers and students are representative of a remarkably adaptive animal. If the teacher wants to work and teach in cooperative teams, and wants the flexibility and freedom of open-planning, then the lack of acoustical separation will not be a concern. The "open plan" schools which seem to be functioning successfully are staffed by teachers who have selected that school and that way of teaching, and have not been put in the situation against their wishes.



- Total acoustical separation between groups and functions cannot be achieved in an open plan school. A child working with a teacher in one group will be able to hear students in the next area or the next group; he will be able to hear and see students as they pass from group to group; he will hear the sound of the projector or televised program in an adjacent area.

- Students evidently can learn and work effectively in an open plan if the teacher does not influence them otherwise, and if they are physically equipped to hear and see as well as their classmates.

- Extensive use of acoustically absorptive material can "dampen" the noise inherent in open planning. Carpeting seems essential, as well as acoustically treated ceilings and as many acoustically treated permanent sidewalls as possible.

5. The use of recorded sound in open planning does pose problems, and will often disturb others in nearby areas. This problem is particularly complicated when large groups gather together and the recorded sound level must be raised for the entire group to hear. The normal "sounding board" and hard reflective surfaces are not available in the open plan school as these have been treated with absorptive materials to reduce, rather than distribute sound. Therefore, decentralized, low level sound systems should be explored in open plan schools if extensive recorded materials are to be used.

6. Open plan schools are often conceived to allow teachers to work together cooperatively and this appears to a factor in teacher acceptance of a lack of acoustical separation. If teachers in adjacent areas are teaming or working cooperatively toward a total educational process, the disturbance of one group will not be a significant factor to others. However, if the teachers are self-contained and therefore somewhat competitive, as in the typical graded school, then the lack of acoustical privacy and the resultant disturbance among groups seem to become detrimental to effective teaching.

7. It has been observed that where education seems to be taking place effectively in open plan schools, the administration has planned carefully in advance to put together a team of cooperative teachers who are committed to that environment.

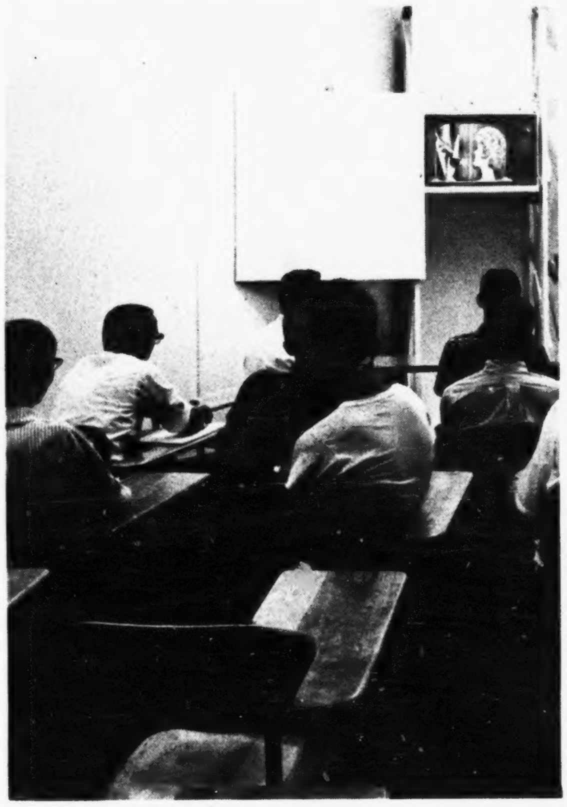
8. Certainly not all educational activities can take place in an open plan building. For instance, commercial classes, such as typing, require acoustical privacy as do band and choral groups. Language programs which require students to respond or to record responses require isolation. In programming a school where open planning is desired, it will still be important to separate and isolate those facilities where acoustical privacy is an important consideration and where a lack of acoustical privacy could significantly reduce the effectiveness of the rest of the teaching program.

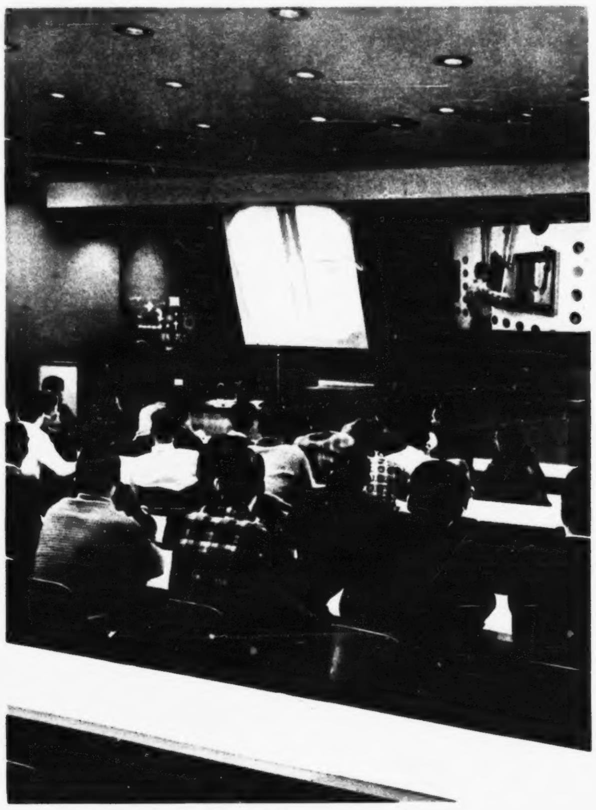
There is very little research which tells us how well students learn in an open or flexible plan or how much adaption to noise is possible before learning is impaired. Until such research becomes available, the acoustical planning of such spaces must proceed on experience and sound judgment.

• SOUND SYSTEMS

An integral part of the acoustical planning of larger facilities are the electronic systems for amplifying sound. The two types of sounds produced in classroom and lecture rooms which require amplification are:

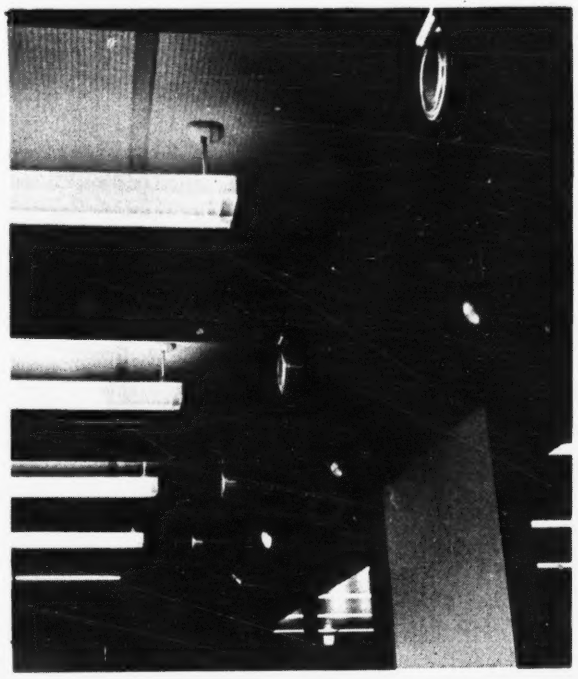
- Sounds reproduced from sound tracks of films and audio tapes, radio, television, and intercom announcements. These will always require some kind of amplification system.
- Live sounds, produced by the instructor and any demonstrations he may use. Although a system for amplifying and distributing these sounds is usually not necessary in well-designed rooms seating less than 300, it is a good idea to make provision for them in the sound system that is provided for recorded sounds.





Two types of sound systems are available for use in large rooms:

- Distributed, low-level systems with speakers located at various points in the ceiling.
- Central, high-level systems with a single speaker (or group of speakers) located at one point and directed at the center of the audience.



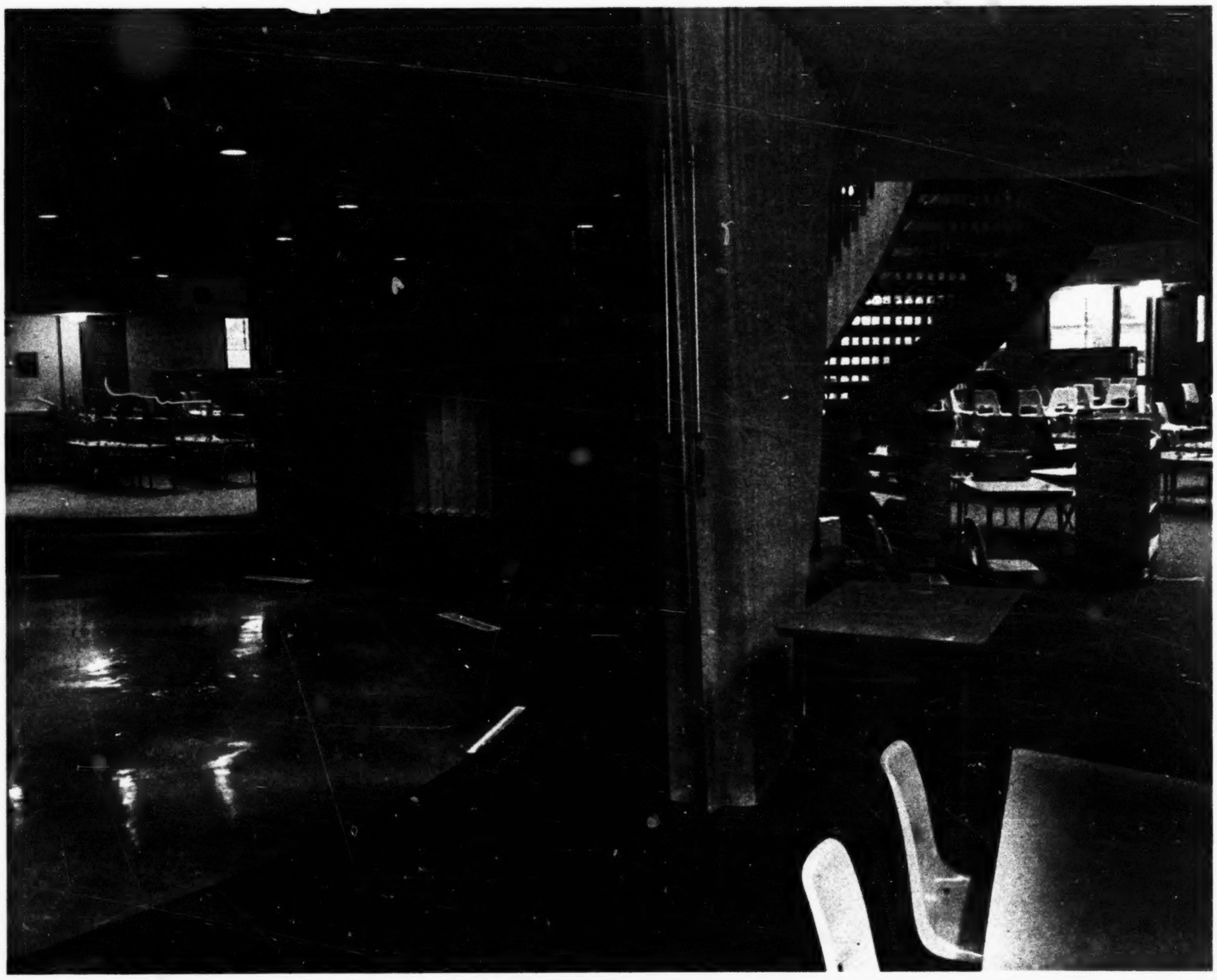
The selection will depend on a number of factors, including reliability, maintenance, a useful life of 15-20 years, tonal quality, and reproduction of complex sounds such as music. The low-level systems are probably most effective for distribution of recorded sounds since the low level helps keep transmission through the walls to a minimum and produces an equal quality and level of sound throughout the room. However, it is important that sounds made by a speaker appear to be coming from his position at the lectern, and this sometimes renders the central system a better choice.

Finally, building-wide sound distribution systems must be considered early in planning. Such inter-communication systems require central space to house the originating, transmitting, and control equipment; each educational facility included in the system must be provided with appropriate speakers, controls, and "talk-back" capabilities. If these systems are particularly extensive or complex, expert advice should be sought to insure proper installation and function.

5

ACOUSTICS AND NOISE CONTROL

- BUILDING ELEMENTS AND SOUND TRANSMISSION
- MECHANICAL EQUIPMENT AND NOISE TRANSMISSION



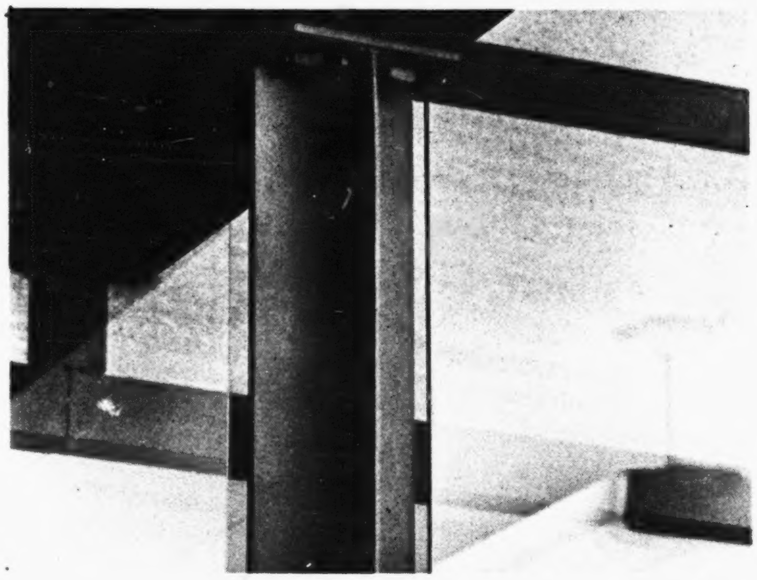
• BUILDING ELEMENTS AND SOUND TRANSMISSION

Sound transmission can be discussed in terms of the various elements of a building transmitting sound. The general transmission characteristics of partitions, for example, can be discussed in terms of partition design without reference to the building of which the partition is a component.

PARTITIONS. Noise transmission through partitions is accomplished in two ways. First, the energy of the sound waves striking the partition causes it to vibrate, in turn activating air particles on the opposite surface; and second, air leaks through or around the partition permit airborne sound to pass through without having to transfer energy to and from the structural barrier. Control of noise transmission, therefore, resolves itself into minimizing the occurrence of air leaks, usually found at floor and ceiling joints and around openings, and incorporating materials with low sound transmission qualities.

Sometimes corridor partitions, which have glazed sections, are designed with an inch or so of space between adjacent pieces of glass in order to simplify detailing and to permit air flow from corridor to classroom. Such partitions, obviously, have little noise-control value. It is essential, when the building program calls for partitions with good noise-reduction capability, that air leaks (whether intentional, as above, or unintentional, as ill-fitting doors) be eliminated.

No matter what the sound reduction qualities of partition construction may be, the presence of air leaks will provide a path for sound travel around the designed obstacle.



construction details can permit sound leaks

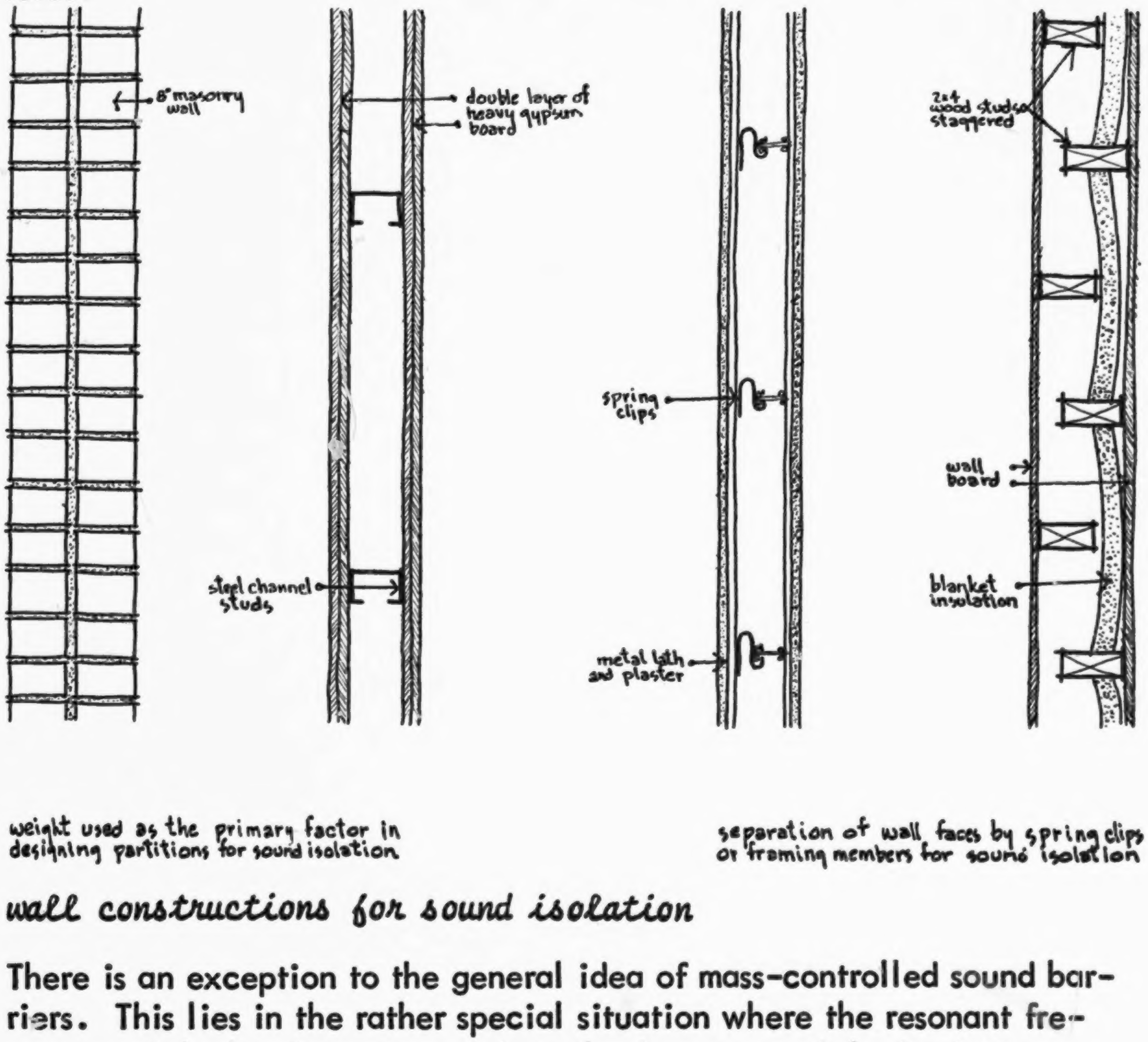
The solution is simple in theory, but not simple in its accomplishment. If one could economically seal all openings into the room against the passage of air, this part of the problem would be solved. But there must be ductwork, doors, and operating windows, and the sealing of these and other cracks in construction requires great care in initial detailing and final fitting.

As mentioned in the previous section, "crack-sealing" techniques must also be utilized for movable and demountable partitions. These may be in the form of gaskets, and pneumatic and mechanical seals.

In terms of construction materials, a common error is to suppose that a partition made up of a porous, sound-absorbing material will be an effective sound barrier. In fact, this may turn out to be the worst kind of a divider, in that it provides air paths through the porous material.

In addition to transmission through air passages, partitions formed of plywood, thin solid plaster, gypsum board, and other lightweight construction can act as diaphragms and become serious offenders in the transmission of sound from one space to the next. In the transmission of sound from space to adjacent space through diaphragm action, the fundamental concern is the degree to which the intervening wall is set into motion by the driving force of the air sound wave striking the opposite side. Several factors are of significance.

The structural ability to resist movement under a force is related to the dimensions of the wall and the material of which it is constructed. However, the motion under the impact of the sound wave is a very rapid fluctuation, and the degree of movement tends primarily to be dependent on the mass of the wall. Under the relatively feeble vibratory impulses of sound waves, a heavy wall will tend to offer high resistance to vibration because of its inertia. Resistance to the passage of sound is exponentially related to the weight per square foot of the structure. It is for this reason that new buildings constructed of light materials tend to have acoustical weaknesses which did not arise in older, heavy-masonry structures.



weight used as the primary factor in designing partitions for sound isolation

separation of wall faces by spring clips or framing members for sound isolation

wall constructions for sound isolation

There is an exception to the general idea of mass-controlled sound barriers. This lies in the rather special situation where the resonant frequency of the barrier corresponds to the frequency of the impinging sound. In this case, mass does not act in a significant way. However, the resonant frequency of most wall constructions is well below the significant sound frequencies, and this becomes a factor only in small, light dividers such as areas of glass.

The most obvious method of increasing the noise reduction capability of a partition, therefore, is simple, at least in theory. It consists of deliberately adding mass for noise reduction purposes; brick, concrete, and even lead and other heavy materials may be used for this purpose.

However, the acoustical value increases only as the logarithm of the mass - and heavy construction tends to be at odds with today's methods. A highly effective system for substantial sound insulation without excessive weight lies in double-wall construction. In its simplest form two walls separated by an air space form the division between two classrooms. A sound wave in one classroom sets the adjacent wall in motion, in turn this sets up a wave in the air space, and finally the second wall vibrates and produces sound in the second classroom.

However, the path involves several changes of media, and the first wall can vibrate almost independently of the second since it is linked to the second only by the elastic air between. Sound transmission is substantially reduced.

The key to success in this type of construction is that of keeping the connection between the two walls at a minimum. The intent will be almost wholly defeated if there are structural connections which allow one wall to activate the other.

Another double construction technique is that of a "lock" or buffer zone between the sound source and the room to be protected. In a conventional school, the corridor can form this separation between rooms. Where quiet conditions are very important, it will be worthwhile to arrange a vestibule entrance with two doors as barriers.

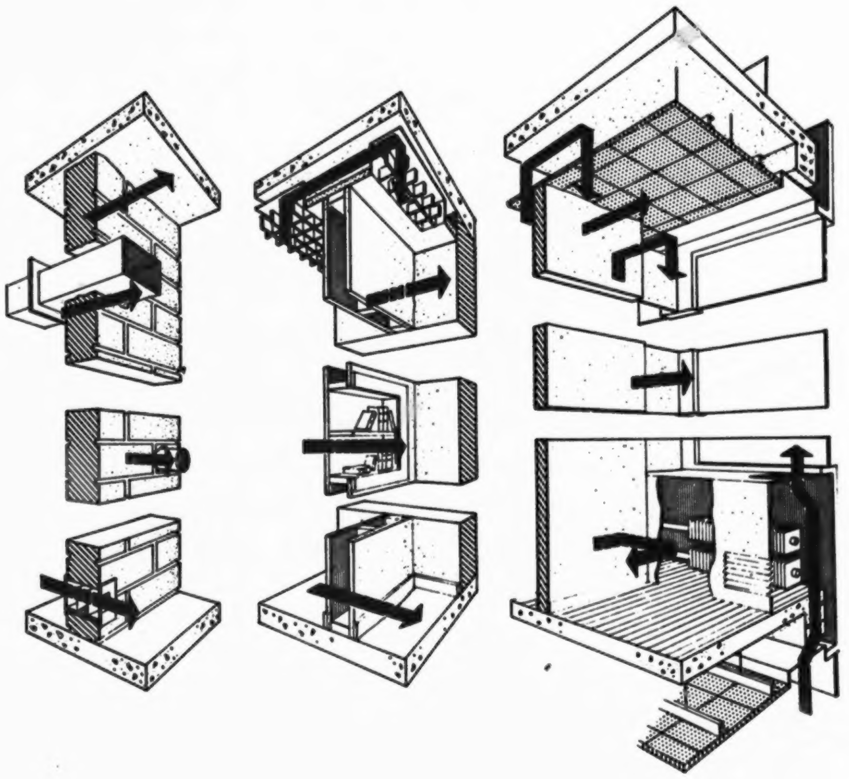
EXTERIOR WALLS. Transmission of sound through exterior walls is divisible into the same major consideration as for partitions - air-borne sound and diaphragmatic transmission.

In New York State, climatic conditions do not demand that windows be kept closed throughout the school year: if mechanical ventilation must be supplemented by the use of windows, the noise-transmission problem is proportionately aggravated. When nearby classrooms have their windows open, the possibility of classroom-to-classroom transmission exists.

Noise can, of course, easily enter an open window from an adjacent room, street or playground. Probably the only complete solution to this kind of problem is the use of fixed windows and artificial ventilation. Baffled ventilators could be provided which would allow air passage and absorb sound, but the expense for a number of windows would be prohibitive. Some benefit has been obtained in avoiding transmission "around the corner" from one classroom window to an adjacent classroom by fins extended out from the face of the building, and by planning of casement windows to serve, when open, as a shield rather than a reflector of sound from one room to the next.

Transmission of sound through doors and windows often raises difficult problems for two reasons. One is the fact that most units are not so well fitted to their frames as to eliminate the possibility of "cracks" at jambs, heads and sills. Through such cracks, of course, the energy of sound waves can pass relatively unimpeded. The other problem is the relative thinness of the glass or wood panels in most windows and doors, and the corollary ease with which such thin surfaces can be energized to vibrate and transmit sound of incident sound waves.

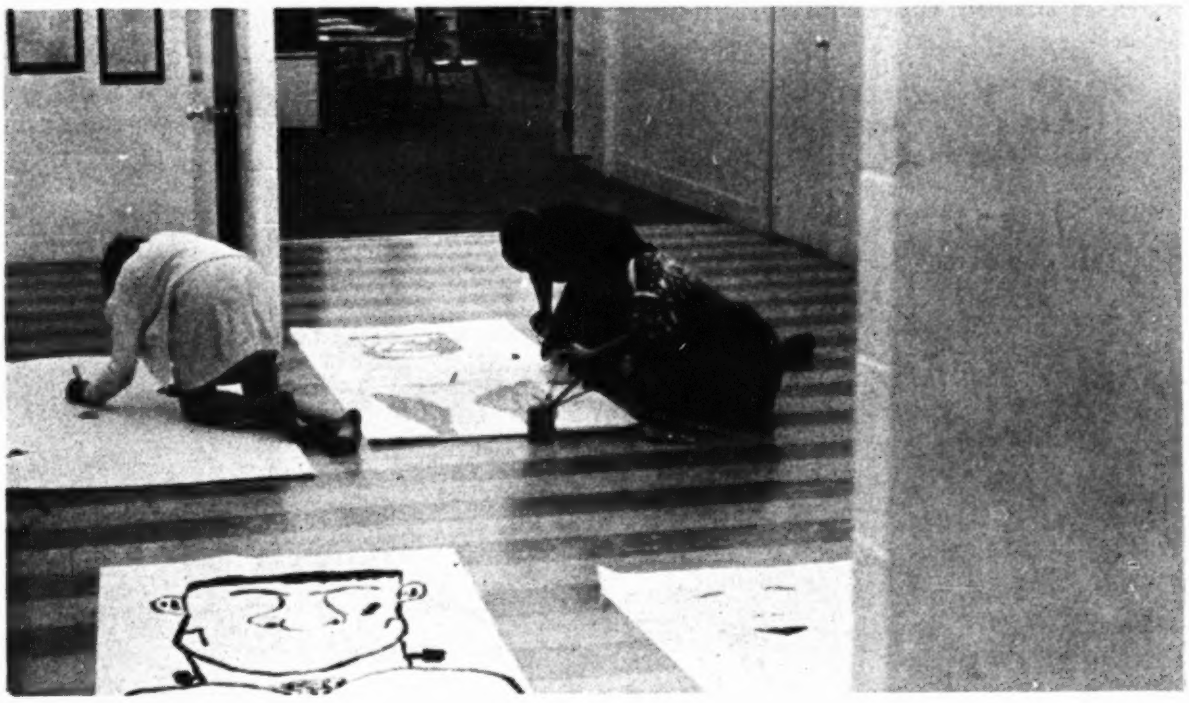
These problems can be combatted. To minimize the crack problem, it is obvious that closely fitted millwork is a prerequisite; further, the use of felt or metal weatherstripping will do a good job of sealing cracks when the door or window is in the closed position. The transmission problem is more difficult, but some suggested remedies include the use of double glazing for windows, and the use of solid cores in door construction.



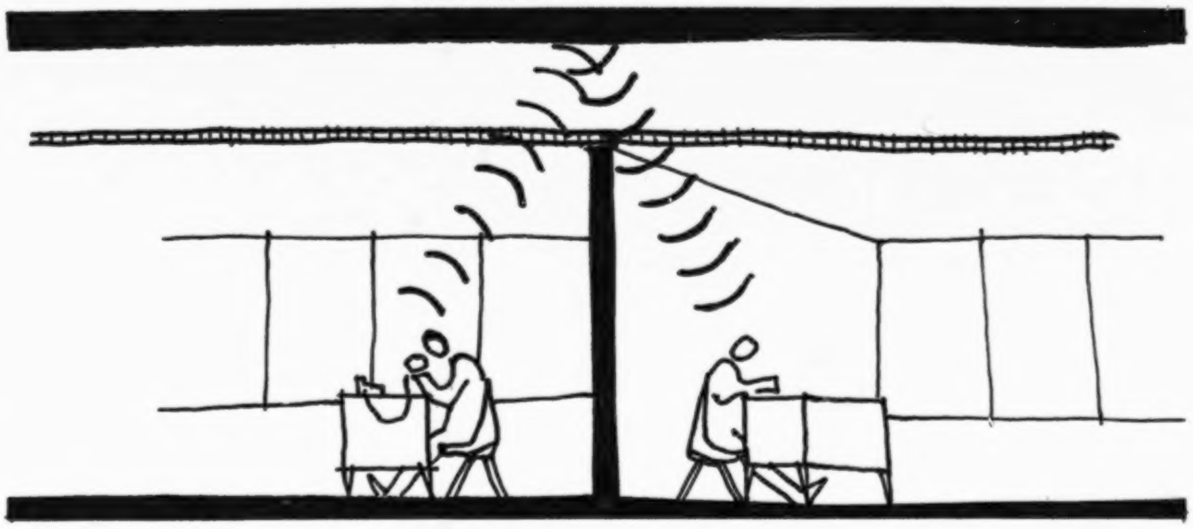
potential sound leakage paths

ROOFS AND FLOORS. In considering roofs and floors, the possibility of "air-path" routes for sound can usually be discounted if the building is reasonably well-built. If transmission to adjacent buildings is not a consideration, there is no need to build-in sound reduction in roof construction; however, if there are environmental noises which might enter classroom areas via the roof, reduction capability must be provided.

Floor construction shares the problem of reducing transmitted noise, but has a special problem of its own - impact noise, resulting from foot traffic, furniture movement, and the like. Floor treatments, such as carpeting, which absorb as much of the impact energy as possible are second only to removal of the noise source as a solution to the problem. Alternately, mass of construction - heavier floor slabs or the introduction of additional sub-floor layers - may be employed. It is essential in planning the use of a given room that the effect of impact noise on adjacent rooms be considered. After the investigation has defined possible problems, an alternate solution such as relocation of activity, heavier construction, or acoustical floor treatment can be selected.



In contemporary school building design, the movement of noise through the space above the finish ceiling and below the floor or roof above is frequently a critical problem, stemming from the fact that interior partitions are often not carried above the finish ceiling. Solutions consist of installing barriers above the ceiling or making the ceiling itself resistant to the passage of sound.



STRUCTURAL TRANSMISSION. Sound vibration through the building frame has its source outside the building (nearby highway or rail traffic) or inside in the form of mechanical equipment noises and vibration. In the former case, if the problem is serious, foundations can be designed as barriers to vibration.

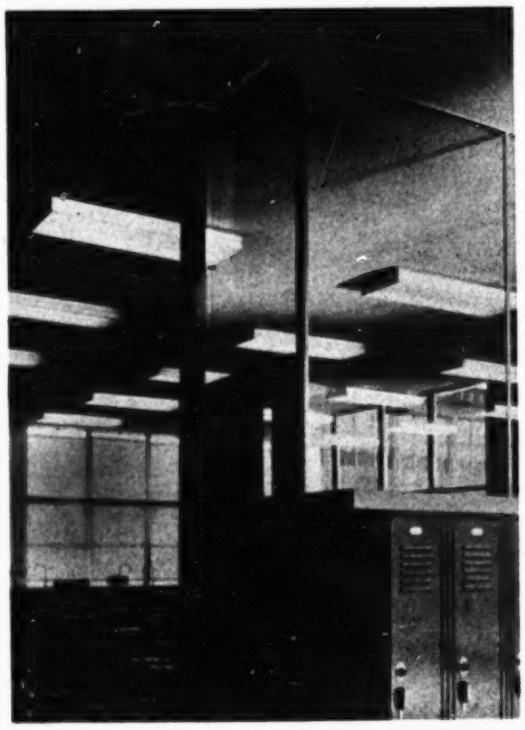
The noise from impact sounds originating within the building are most effectively controlled at their source. Where this cannot be done, some discontinuity must be introduced in the path of the noise to the room, or in construction of the room itself. In many cases of severe noise levels and critical sound problems, the solution of a "room within a room" is the best solution. The expense of this type of construction, however, tends to restrict it to special and critical cases.

• MECHANICAL EQUIPMENT AND NOISE TRANSMISSION.

Heating, air conditioning, ventilating, and plumbing apparatus are notorious sources of noise in structures. The first step in solving such acoustical problems is recognizing how and where the noise will originate, and then proceeding to eliminate , control or isolate the vibrations.

ELECTRICAL. With a few exceptions, electrical apparatus, exclusive of motors and similar devices associated with air conditioning systems, is not a source of noise. The exceptions are devices which produce alternating electro-magnetic fields, such as power transformers and the ballasts of fluorescent lighting fixtures. Power transformers are usually located in vaults surrounded by heavy construction which is normally sound- isolating, or they are out-of-doors. Sound levels are specified by the manufacturers. Attention to the transmission of sound through vault walls, or the location of transformers away from open windows will be sufficient to solve this kind of problem.

Fluorescent lamp ballasts present a more difficult problem. The problem is complicated because the final noise level is dependent not only on the ballast but on the construction of the fixture itself. Provision should be made in specifications to restrict the noise level to published rating scales, and to provide for replacement of an occasional ballast which may produce excessive noise.



fluorescent lights - and lockers - provide potential sources of noise

PLUMBING. Plumbing systems can be annoying sources of noise. Motors and pumps, as a part of the supply and circulation system, can produce noises which transmit themselves quite easily through the piping systems to various rooms. Toilet fixtures are a source of noise, and poorly located shower rooms will be a source of noise which could be annoying in adjacent rooms.

Normally, circulating or well pumps will be located at a distance from any rooms where their noise might cause difficulty. However, this does not solve the problem of transmission along pipelines. The most satisfactory solution to these vibrations is the introduction of a flexible connection in the otherwise metallic piping system. This connection can be of rubber, rubber and fabric, or plastic and should be located near the pump.

It may be necessary to suspend the piping on resilient supports to avoid vibrations entering the structure. Vibrations of this nature may not only originate with pumps, but can be the result of noisy flow in the pipes themselves.

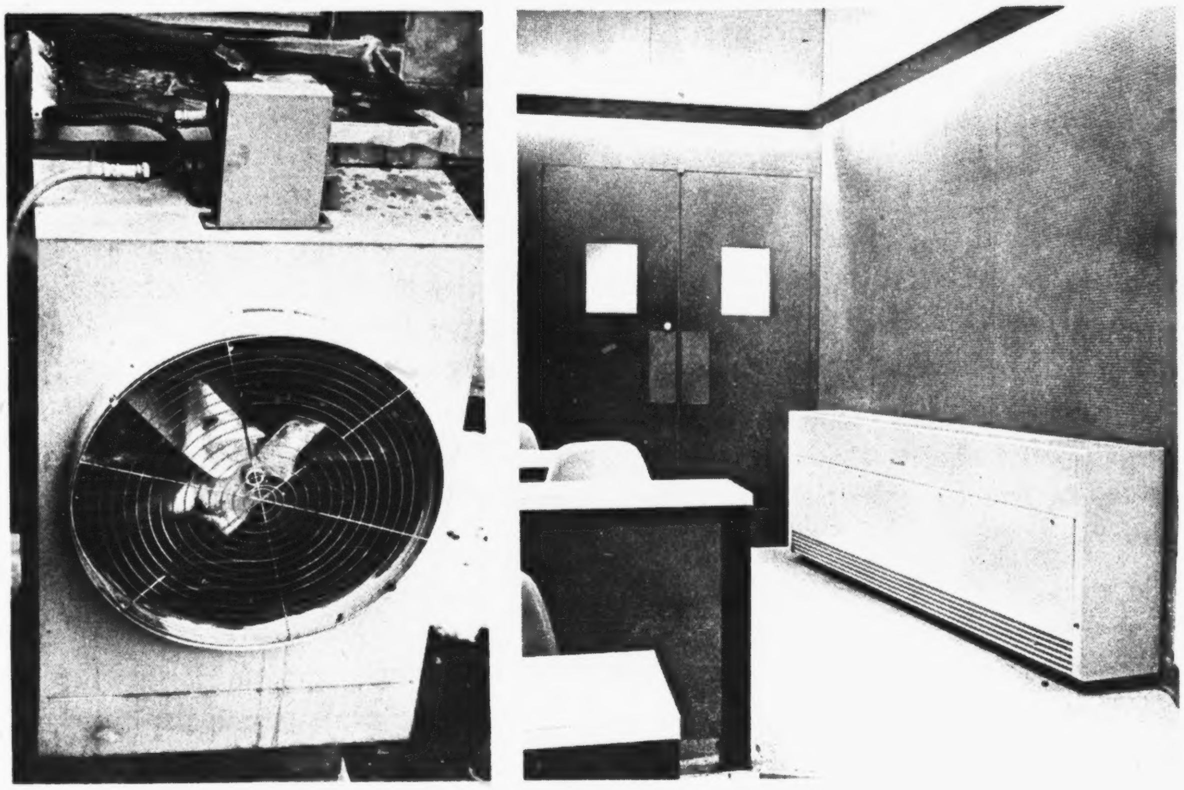
Sanitary and storm drainage piping involves a very complicated pattern of liquid flow and air movement occurring at the same time. These lines should be located within pipe spaces or chases rather than exposed in rooms. If the location is such that such noises might be significant and the velocity of discharge may be high, provisions should be made to pack the space with sound-deadening material. Because there may be a tendency for this kind of noise to get into the structure through metallic supports, resilient connections between piping and basic building structure may be advisable in certain cases.

Another kind of piping noise arises from "water hammer". This is a jarring noise that results from the sudden stopping of the flow of a body of water when a control valve, such as a lavatory faucet, is closed. The inertia of this substantial body of water exerts a force of some magnitude through the piping, and particularly against valves in the system. The solution is the use of air chambers, usually located at the individual fixtures, or the introduction of units especially manufactured for this purpose.

Perhaps the most common annoyance from a plumbing system arises from the flushing of fixtures in a toilet room. Water closets and urinals are discharged by flush valves which must function by producing a rapid and heavy discharge of water. There are variations in the sound produced by fixtures and valves, and attention should be paid to selecting equipment with low noise levels. However some noise is inevitable, and it tends to get into the piping system and the walls surrounding the toilet, and to continue from there to classrooms. It is advantageous to arrange toilet rooms back-to-back, with toilet fixtures on the dividing wall, instead of adjacent to a classroom. Piping which might cause noise to be radiated to sensitive areas should be supported by resilient hangers.

HEATING, VENTILATING AND AIR-CONDITIONING. All major components of heating, ventilating, and air-conditioning systems are a source of noise problems. For convenience in discussion, they might be divided into four types:

- Equipment located in the room and introducing sound energy directly into the room.
- Equipment located out-of-doors, and an annoyance when sound enters into the building.
- Equipment of a central station nature, such as pumps, chillers, fans.
- Duct work which can be both originator and transmitter of noise.



Equipment located in the room consists of diffusers, grills, registers, unit air conditioners, unit ventilators, and the induction coil units often used with high velocity systems. These sources feed sound energy directly into the room, and the means of control are restricted.

The simplest and best solution is selecting sufficiently quiet equipment. In this and other aspects of the noise problem with mechanical equipment, it is important that preventive maintenance eliminate worn bearings and parts which will produce noise.

With a constant energy input from such devices as grills or unit air-conditioners, the level of steady ambient noise will depend upon the amount of absorbing material in the room. The average noise level can be reduced by increasing the absorption of a room, but this is often not desirable since the acoustical character of the room will be adversely affected.

It might be noted that inlet grills constitute a flexible means of providing noise to mask sounds which should not be heard. From manufacturers' data it is possible to determine and control the air velocities which will produce desired levels of noise. Adjustments are also possible through the use of dampers.

The most common device located out-of-doors is a cooling tower for a refrigeration system or an air-cooled condenser which performs the similar function of dissipating, to the atmosphere, heat removed from the interior of the building. In addition diesel generators, pumps, and ventilating fans may be located outside.

If these devices are connected by pipe runs to the building frame, and if there is substantial vibration which might be transmitted to the building frame, there should be resilient sections to interrupt these paths of travel in the same way that vibration is isolated from the structure in the mountings of motors, compressors, and other mechanical equipment inside the building.

If the device is not surrounded, in whole or in part, by walls, the attenuation of sound will approximately follow the inverse square law and decrease six decibels for each doubling of the distance from the source.

This is quite a rapid rate of energy loss and can be used to gauge the limits of nearness to points such as an open window where sound might be an annoyance in a classroom. For example, a machine located thirty feet away, but with a 50 decibel noise reading at the classroom window, could be removed to 60 feet and reduce the noise to a 44 decibel level.

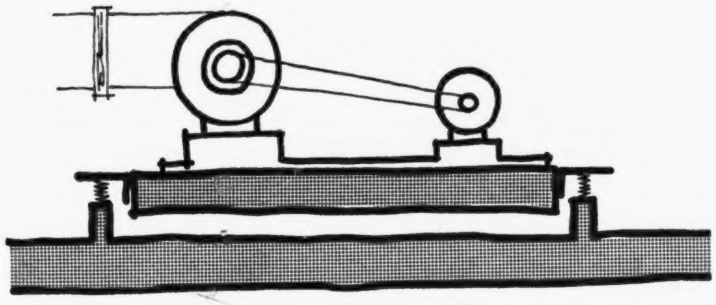
For the third type of sound source, the central station equipment involves fans, motors, boilers, burners, pumps and compressors; there are two possible means by which noises from these devices can cause difficulty.

The first, the simplest, is a situation where a boiler room, or other type of mechanical equipment room, is separated from an adjacent critical hearing space only by a partition. For this situation, the problem is the same as the transmission of sound from one classroom to another, except that the sound in the mechanical equipment room is likely to be much higher in intensity. Normally one would expect these rooms to be located away from critical hearing areas; such planning should be encouraged.

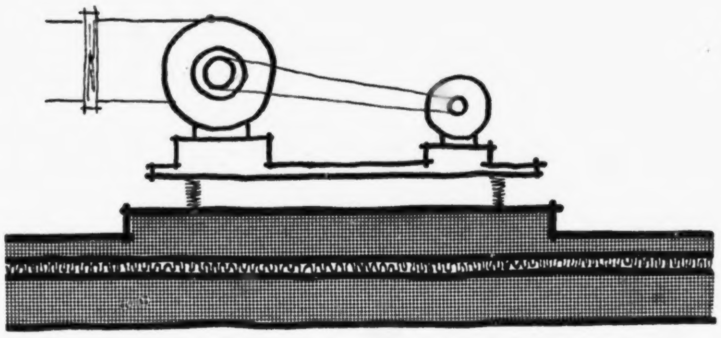
The second kind of difficulty arises from vibrations of mechanical apparatus which travel through the elastic frame of the structure and cause vibrations of room surfaces, possibly some distance away. Rotating and reciprocating engines are common causes of this kind of problem.

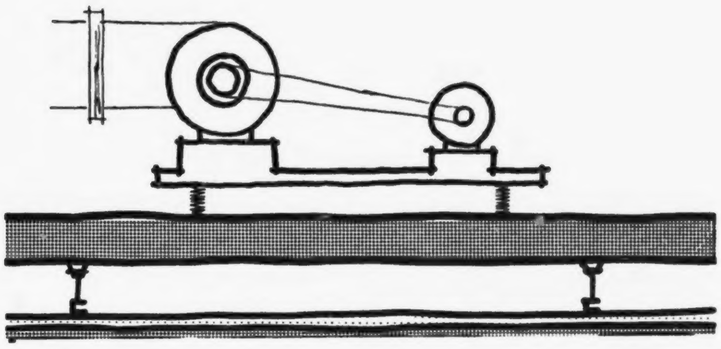
The cyclical vibrations of motors, compressors, pumps, and the like, if these machines are of sufficient mass, and if they are securely bolted to the surrounding structure, can be transmitted through the structure to permeate the building. If the machine cycle frequency is of the order of 20 cycles per second or less, it can be sensed as vibrations; if it is significantly exceeds this figure, it can be sensed as noise,

In this latter case, the problem is one of separating the vibration-generating equipment from the building structure and from connecting ductwork. Many types of supports are available: an excellent treatment of the subject may be found in the ASHRAE Guide and Data Book.



methods of reducing vibration and noise





The fourth classification of mechanical equipment noise covers the noise-generating and carrying capacity of duct work. The shaking and rattling of loose components such as registers, cover plates, duct hangers, and walls, create noises which are carried by the ductwork into each ventilated room. These can be eliminated through careful assemblage, fastening, and maintenance of equipment. Where experience dictates, non-metallic washers, spring covers and the like can be employed to prevent metal-to-metal contact. Vibration of excessively large thin sheets of metal can be corrected by cross-breaks or reinforcement.

In addition to the noise conducted by duct work and generated directly by the mechanical equipment, other sources are:

- Turbulance at the fan as a result of high velocity air movement near the blades.
- Vibrations from the fan housing which enter the duct system and are transmitted by it.
- Air noises from high velocity air flow.
- Turbulance in the duct system as a result of poor streamlining.

- Cross-talk in which sound from one room enters the duct system, and, because of the duct layout, need travel only a short distance to enter another room.

In combatting these noise problems, several points should be considered:

1. It is important that fans be properly sized and selected, and run at their most efficient speed and under friction heads for which they were designed.
2. Air noise increases exponentially with the velocity and is caused, in many cases, by turbulence resulting from excessive velocity and lack of careful attention to the streamlining of the duct system.
3. Where acoustical control is of great importance, the added expense of low air velocity with larger ducts and fans is well justified.
4. Consideration should be given to the use of acoustically absorbent linings in the duct systems to absorb some noises. This will not, however, take care of improperly designed inlet grills where too high a velocity and poor streamlining can cause introduction of noise into the room.
5. A common error which is easily avoided is that of arranging short ductwork connections between rooms so that noise in one classroom passes through a short length of ductwork and into an adjacent room.
6. Round ducts are much more resistant, by their physical form, to noises from vibration of the metal. For high-velocity ductwork, round ducts are necessary, and acoustical absorption is used to reduce air noise.
7. If the normal ductwork layouts do not provide for sufficient suppression of noise, it is then necessary to introduce porous absorptive material as a lining in the duct system.

For economy in heating and air conditioning, it has become common to use individual room units which contain fans, filters, and the other devices for air handling, and to supply to the room only piped hot and possibly cold water. This may aggravate the acoustical problem if these self-contained cabinets and their apparatus are not carefully designed for acoustical control. Generally, they are mass produced for a highly competitive market, and the acoustical characteristics tend to be at a minimum. The problem is difficult to correct when the sound source exists in the room, a quite different situation from that of a central fan system where the intervening ductwork can have acoustical absorption.

The procedures for computing the amount of absorption required are found in a number of standard references. In general, an evaluation is made in terms of the number of decibels lost per foot of ductwork lined with a given material, based on a desirable design level for the room. There is also a measurable level of disturbing noise at the point of origin. The difference between these values is the amount of attenuation that must be provided through the path from the source of noise to the ear of a listener in the room. The losses occur as a result of the formation, length, materials, acoustical treatment, and other characteristics of the ductwork. Noise which may be regenerated at the inlet grills by turbulance must be considered along with the sound energy lost by "room effect" where sound entering at a certain level from the grill is reduced in its average intensity as the sound is distributed and absorbed through the volume and by the surfaces of the room.

Each of these factors of sound attenuation and sound gain are subject to quantitative evaluation. Those working with mechanical systems for schools should be familiar with these processes, and should consider them an important contribution toward providing an acoustical environment appropriate to the purposes of a school.

CREDITS AND SOURCES

SOURCES OF DIAGRAMS AND TABLES

1 Handbook of Noise Measurement; A. P. G. Peterson and E. E. Gross, Jr., General Radio Company, West Concord, Massachusetts, 5th Edition, 1963, Page 4, Fig. 2-1.

2 Page 16, Fig. 3.3.

3 Acoustical Designing in Architecture; V. O. Knudsen and C. M. Harris, John Wiley and Sons, Inc., Seventh Printing, December 1963, Page 21, Fig. 2.2.

5 Page 168, Fig. 8.13.

4 Time-Saver Standards - A Handbook of Architectural Design; J. H. Callender, Editor, McGraw-Hill Book Company, Fourth Edition, 1966, Page 638, Fig. 38.

6 Page 617, Table 1.
9 Page 618, Table 9.
11 Page 620, Fig. 10.
14 Page 636, Fig. 32 and Page 637, Fig. 33.
15 Page 638, Fig. 37.
17 Page 637, Fig. 35.
18 Page 638, Fig. 36.

10 Acoustics in Architectural Design; Leslie L. Doelle, National Research Council of Canada, Division of Building Research, Ottawa January 1965, Page 101, Table E.1.

12 Criteria for Acoustic Treatment for University Buildings, (Interim Report), Bolt, Beranek and Newman for the State University Construction Fund of New York, 16 July 1965, Page 7, Table I.

7 Following Page 7.

8, 13 Abstract of appropriate room criterion sheets.

16 New Spaces for Learning, H. D. Hauf et al., School of Architecture, Rensselaer Polytechnic Institute, Troy, N. Y., Design Study J.

PHOTOGRAPHS

All photographs by Carl Howard and the Office of Institutional Research, Rensselaer Polytechnic Institute, Troy, N. Y., except:

Page VI - Louis Reens, 27 West 96th Street, New York City, N. Y.

Page VII - A-V Service Center, San Jose State College, San Jose, Calif.

Page 9 - Handbook of Noise Measurement, General Radio Company, 5th Edition, Pages 27 and 28.

Page 34 - Louis Reens, 27 West 96th Street, New York City, N. Y.

Page 39 - Perkins and Will, Architects, Chicago, Ill.

Page 48 - John Shaver, Architect, Salinas, Kansas.

Page 60 (bottom) - Orlando R. Cabanban, Photography of Architecture, Oak Park, Ill.

Page 87 (bottom) - Time Saver Standards, McGraw-Hill Book Company, Fourth Edition, Page 633.

INDEX

absence of sound 26
absorption coefficient 8
absorption of sound 62
acoustical intimacy 68
acoustical separation 77, 72, 24
"add-on" solutions 38
air conditioning and ventilating equipment as a source of noise 92
auditeria 65

balance 69
balcony design 65
beneficial use of noise 21
block plan 43
brilliance 69

cafetorium 65
campus plan 47
ceiling height 61
center of curvature 61
clarity 69
cluster plan 48
corridorless plan 51
corridor plan 44
courtyard plan 46
crack problem 46
crack-sealing 74, 84
cross-talk 96
cycles/second 5

decay of sound 55
decibel 5
demountable partition 75
diaphragm effect 85
diffraction of sound 10
diffuse reflection 10
directionality 11
double-wall construction 84

echoes 12
effective pressure 5
elastic linkage 67
energy 83, 3
environmental conditions 12
exterior walls 86

feedback 61
finger or pavillion plan 45
flexibility 73, 76
flourescent lamp ballasts 90
focusing of sound 61, 63, 11
furnishings, for sound absorption 66, 64, 57, 21

gymateria 65
gymatorium 65

hearing, quality of 56
heating, equipment as a source of noise 92
human impairments 12

impact noise 88

joint occupancy plan 52

liveness 69
lock 85
loft plan 50
loudness 7
loudness level 7
loudness of direct sound 69

INDEX

masking 11
microbar 5
movable partition 73, 66

Noise Criterion Curve 22
non-load bearing partition 76
noise-reduction coefficient 8

open plan 78, 77, 26, 49
open planning 73, 76
open-plan school 26

partitions 83
percentage syllable articulation 20
phon 7
plan types 42
plumbing systems as a source of noise 91
programming 15

quality of sound 18

reflection at surfaces 10
reflection of sound 64, 61, 56
room length to width ratio 59
reverberation time 60, 27, 9

sabin 8
seminar rooms 71
shape of ceiling, reflective quality 61
site planning 36
site selection 40, 39, 35, 24
sloping floor 69, 59
sounding board 78, 61
sound level meter 7
stepped seating 59
sound-survey meter 9
sound systems 79
sound transmission 87
structural transmission 89

topographical shields 41, 39
tonal quality 69

uniformity 69
unwanted sound 4

wanted sound 4
watt/square centimeter 5

BIBLIOGRAPHY

I. REFERENCES FOR BASIC PRINCIPLES AND GENERAL INFORMATION

Books and Reports:

Acoustics in Architectural Design
Leslie L. Doelle
National Research Council of Canada, Division of Building Research
January, 1965.

Text and bibliography on the technical and mechanical aspects of acoustics, including general information, room acoustics, and noise control.

Acoustical Designing in Architecture
V. O. Knudson and C. M. Harris
John Wiley and Sons, Inc.
December 1963.

General text on acoustics including properties and principles, materials and construction, special spaces, sound systems, and measuring devices. Also contains technical data.

Building Construction
W. C. Huntington
John Wiley and Son's, Inc.
1963.

Reference text and bibliography concerning basic principles.

Criteria for Acoustic Treatment for University Buildings (interim report prepared for the State University Construction Fund of New York)
Bolt, Beranek, and Newman, Inc.
July, 1965.

Technical guide covering general principles, ambient noise levels, reverberation, useful sound reflection, echoes, flutter, sound transmission, and sound amplification. Also contains room criteria sheets and references.

Design Criteria for Learning Spaces
Koppes, Green, and Gassman
Center for Architectural Research, Rensselaer Polytechnic Institute
1964.

General principles of acoustics as well as critique of the experimental classroom at Rensselaer.

Economy Handbook of the State of New York
N. Y. S. Commission on School Buildings
November 1953.

Complete source for construction and checklist of acoustical treatment.

Educational Facilities with New Media, Report C
Green, Gassman, Koppes, Caravaty, and Haviland
Center for Architectural Research, Rensselaer Polytechnic Institute
December 1965.

Basic source which gives a general picture of the problems involved with acoustics including a discussion of hearing, sound systems, construction, and sound isolation.

BIBLIOGRAPHY

Educational Specifications for American Samoa
Western Regional Center, Educational Facilities Laboratory
School Planning Laboratory,
Stanford University
April 1964.

General description of basic acoustical requirements on p. 7.

Educational Specifications for a New Multi-Use Instruction Center, Clark County, Nevada
Western Regional Center,
School Planning Laboratory,
Stanford University
June 4, 1959.

On page 36 there is a discussion of "color decoration and acoustics."

Handbook of Noise Measurement
Peterson and Gross
General Radio Company
1963.

General text discussing principles, measurement, noise control and vibration. Includes references and tables.

Less Noise - Better Hearing
H. J. Sabine
The Celotex Corporation
1950.

General text discussing principles, materials, special spaces, and treatment.

New Spaces for Learning
(revised)
Hauf, Koppes, Green, Gassman, and Haviland
Center for Architectural Research, Rensselaer Polytechnic Institute
June 1966.

Page 33, "Design Factors," discusses the basic problems involved with acoustics in learning spaces.

School Environments Research
No. 1
C. T. Larson, Director
The University of Michigan
1965.

On pages 75-85 discussion of learning and page 483, discussion of sonic environment. Includes psychological reactions and task performance.

Sound Control and Thermal Insulation of Buildings
P. D. Close
Reinhold Publishing Company
1966.

General text covering all aspects of acoustical construction.

Time Saver Standards, 4th Edition
J. H. Callender, Editor
McGraw-Hill Book Company
1966.

Pages 609-648 general text discussing acoustical principles and construction. Contains many tables and graphs.

BIBLIOGRAPHY

Articles - Publications - Pamphlets:

Building Products
"The Broadening Range of Sound Control",
p. 19, special report by the editors
Hudson Publishing Company
February 1964.

This article contains general information about noise, noise measurement, research, products, problems, sound control, design, and technical data.

Canadian Building Digest
"Sound and People"
T. D. Northwood
Division of Building Research,
National Research Council, Canada
May 1963.

Discusses general properties and measurement of sound as well as technical data. Also discusses subjective properties.

Digest of Practical Acoustics
United States Gypsum Company
1954.

Rules of thumb of acoustics on p. 54, as well as sales information and installation methods.

American Standard Acoustical Terminology
American Standards Association
1951.

Extensive collection of terminology and definitions regarding acoustics.

Environmental Engineering for the School
U. S. Department of Health, Education, and Welfare
U. S. Government Printing Office
1961.

Chapter III contains general information including sound sources, planning, treatment, surveys, and special use spaces.

The Journal of the Acoustical Society of America
American Institute of Physics
November 1958.

Discussion of various topics in the field of acoustics.

The Nation's Schools
"How to Keep School Noise at the Right Level", P. 64
Ronald L. Mcay
"How the Experts Solve Noise Problems"
William J. Cavanaugh
McGraw-Hill, Inc.
October 1964.
"Planning Schools for Good Hearing"
L. J. Williams
Bolt, Beranek, and Newman, Inc.
May 1961.

A Picture Story of Architectural Acoustics and Acoustic Materials
Acoustical Materials Association
undated.

Simple description of all basic principles of acoustics.

BIBLIOGRAPHY

Planning Schools for New Media
Bernardis, Doherty, Hummel, and Brubaker
U. S. Department of Health, Education, and Welfare
Office of Education
1961.

On page 27 there is a general description of sound control in classrooms. Multipurpose rooms are discussed on page 43.

The Use of Architectural Acoustical Materials
Acoustical Materials Association
1963.

Contains a basic description of sound problems, sound conditioning and sound isolation as well as technical data.

Noise Control
"Acoustical Study of Carpeting in a High School"
Rodman and Kunz
January-February 1961.

II REFERENCES FOR CASE STUDIES

Books and Reports:

New Spaces for Learning (Revised)
Koppes, Green, Gassman
Center for Architectural Research, Rensselaer Polytechnic Institute
1966.

Discussion of general principles and critique of experimental classroom at R.P.I.

Profiles of Significant Schools
Educational Facilities Laboratories Inc.
Belaine Elementary
Heathcote Elementary
High Schools 1962
Montrose Elementary School
Newton South High School
P.S. 9, N.Y.C.
Saginaw Middle Schools
Schools for Team Teaching
Schools Without Walls.

Articles - Publications - Pamphlets:

Better Light Better Sight News
"The School of Tomorrow"
Dr. Owen Hill
Better Light Better Sight Bureau
November-December 1963.

Discussion of success of acoustical ceiling.

Divisible Auditoriums - Bolder City, Nevada
Educational Facilities Laboratories, Inc.
May 1966.

The Engineering Journal
"The Isolation of the Buildings in the Place Ville de Marie Development from Railroad-Induced Vibrations"
Brett
Engineering Institute of Canada
November 1962.

Progressive Architecture
"Design for Hearing Principles and Case Studies"
Reinhold Publishing Corporation
May 1959.

III REFERENCES FOR SPECIAL SPACES

Books and Reports:

Buildings and Facilities for the Mathematical Sciences
Frame and McLeod - Educational Facilities Laboratories, Inc.
Conference Board of the Mathematical Sciences
1963.

General considerations and treatments for these kinds of spaces.

The College and University Fine Arts Center
Perkins and Will and College and University Business Magazine
December 1960.

On page 28 discussion of sound control in music rooms.

Planners and Planning
Community College Planning Center
Stanford University
(undated)

Discusses outdoor lecture areas, movable partitions, and a number of other spaces.

Profiles of Significant Schools, Schools for Team Teaching
Evans Clinchy
Educational Facilities Laboratories, Inc.
1961.

Discussion of the kind of spaces needed for team teaching.

BIBLIOGRAPHY

Profiles of Significant Schools, Schools Without Walls
Educational Facilities Laboratories, Inc.
(undated).

Discussion of problems of open planning.

The School Library
R. Ellsworth and H. Wagner
Educational Facilities Laboratories, Inc.
April 1964.

On page 15 a description of sound levels and sound problems of the library space.

Articles - Publications - Pamphlets:

An Auditorium Teaching Facility
The University of Texas
The University of Texas Printing Division
1963.

Discussion of sound requirements and acoustical treatment.

Divisible Auditoriums
Educational Facilities Laboratories, Inc.
May 1966.

Discussion of basic problems and a number of plan types.

Forum
"Big Top for Teaching"
Time, Inc.
May 1961.

Discussion of teaching space in a dome.

Impact Noise Control in Multifamily Dwellings
Bolt, Beranek, and Newman for the Federal Housing Administration
January 1963.

Discusses the problems and solutions for impact situations.

New School Stages for Old
J. H. Miller
Hub Electric Company, Inc.
(undated)

A Planning Guide for Vocational-Industrial and Vocational-Technical Building Facilities for Comprehensive High Schools.
Division of School Buildings and Grounds, the State Education Department of New York.

Discussion on page 30 of acoustics in shops.

Space/Aeronautics
"How to Protect Yourself Against Noise"
Odend'hal
reprinted for: Jamison Cold Storage Door Company
June 1959.

Discussion of the isolating doors in aeronautics testing laboratories.

Study Carrels
Educational Facilities Laboratories, Western Regional Center
(undated)

Discussion of acoustics in study carrels on page 5.

A Study on Studying
Community College Planning Center
Stanford University
(undated)

Discussion of criteria for study spaces.

Music, Acoustics, and Architecture
L. L. Baranek
John Wiley and Sons, Inc.
1962.

IV. REFERENCES FOR MATERIALS AND PRODUCTS

Articles - Publications - Pamphlets

The American School Board Journal
Bruce Publishing Company
December 1965.

Page 12 Carpet Maintenance and Selection - Wyman
Page 13 Flooring - A Vital Environment - Campbell.

Cutting Costs with Carpet
American Carpet Institute
1963.

Contains four case studies and compares carpet with other materials for properties and cost.

Excellence and Economy
American Carpet Institute
1965.

A report on the benefit of carpeting in 3 case studies.

Improved Sound Barriers Employing Lead
Lead Industries Association
(undated).

General description of use, comparisons, and technical data.

BIBLIOGRAPHY

V. REFERENCES FOR SYSTEMS AND EQUIPMENT

Books and Reports:

First California Commission on School Construction Systems
July 1963

Contained the technical specifications for SCSD.

Recommendations for Impact Noise Isolation in Multifamily Dwellings
Bolt, Beranek, and Newman, Inc. for the Federal Housing Administration
January 1963.

Discussion of the impact problem and possible solutions.

Articles - Publications - Pamphlets:

The Answer to a Challenge
Inland Steel Products Company
(undated)

Discussion of acoustical aspects of SCSD.

Gym Divider Curtains
bulletin by Wald-Porter
athletic equipment

Describes new type gym divider curtain.

New Movable Component Classrooms
E. F. Hausermen Company
1965.

Sales bulletin demonstrating how good acoustics is possible with movable partitions.

Progressive Architecture
"Isolation of Railroad/Subway Noise and Vibration
L. N. Miller
reprinted for Lead Industries Association, Inc.
April 1965.

Design and technical data.

Television in the Classroom
Canadian Broadcasting Corporation
November 1954.

General information about value and use.

VI. REFERENCES FOR TECHNICAL DATA

Books and Reports:

Handbook of Noise Measurement
(see general references)

Articles - Publications - Pamphlets:

Comparison of Wall Costs
Handbook of Wall Design, No. 1
Robinson Brick and Tile Company.

Performance Data Architectural Acoustical Materials
Acoustical Materials Association
January 1966.

School Building Costs
Koppes and Callender
Owens-Corning Fiberglass Corporation
September 1957.

Sound Absorption Coefficients for Architectural Acoustical Materials
Acoustical Materials Association
1960.

A CHECKLIST FOR PLANNERS AND ADMINISTRATORS

This checklist was developed to help summarize the points covered in this guide, and to give architects and administrators a tool for checking acoustical considerations at various stages in the programming, planning and equipping of schools.

PROBLEMS OF NOISE ON AND NEAR THE SITE

Traffic on nearby roads

- -what is the present density?
- -what can be predicted about future growth of traffic?
- -what legal controls exist or should be instituted, as a type of zoning, to maintain an appropriate acoustical environment for the neighborhood?
- -does the traffic problem include heavy vehicular units such as trucks or buses?
- -from available studies what sound levels can be predicted at various points on the periphery as a result of road traffic?
- -what arrangements of grading and building design and location will shield sensitive areas from intruding sound?
- -what areas of trees and shrubs can help shield and absorb traffic sounds?
- -can trees be maintained and supplementary plant growth be provided for this purpose?
- -what sound levels can be determined for various points on the site as a result of exterior road traffic?

Air traffic

- -what are the existing and projected air-traffic patterns, particularly in connection with the location of public or private airports or airstrips?
- -does or should, zoning control future hazards?
- -what are the probable sound levels from aircraft?
- -does the location near landing strips or in the path of low-flying planes make the site impossible within reasonable economic limits?
- -what barriers of trees, contours or buildings can shield sound from sensitive areas?

Rail traffic

- -what are the present and future rail traffic patterns near the site?
- -are there special noise problems of climbing up grades or of crossing signals?

- -what are the provisions for shielding and deflecting air-borne sound by contours, planting and structures?
- -what are the probable sound levels at various points on the site?
- -are there possible difficulties from vibrations through the earth which might enter structures through the foundations?

On-site

- -will roads, parking lots, side walks and other circulation areas produce troublesome noise?
- -how can playgrounds, assembly areas, bus platforms, and organized sports areas be planned to reduce noise problems?
- -are there natural features such as rivers, rapids, and waterfalls which might cause problems?
- -are there building uses such as boiler house, maintenance shops, wood and metal-working shops, electric substations, cooling towers, field houses, and band practice buildings which can contribute to site noise?
- -what are the probable sound levels at various points on the site?

Summary of site noise problems

- -determine the total effect of road, rail and air traffic, on-site and adjacent site noise, and other special sources of site noise problems
- -combine in terms of frequency and energy levels
- -take into account significant time variations for each source
- -identify problems of acoustically sensitive outdoor activity areas
- -identify sound levels at significant points in the proposed school for future use in computing sound insulation values of enclosing walls
- -consider design articulation of outdoor spaces in terms of noisy and quiet areas which can be controlled in part by shielding and absorption by walls, trees, grass and shrubs or made lively by paving, hard building surfaces, and admission of outside noise.

PROBLEM OF NOISE WITHIN BUILDINGS

Mechanical, plumbing, and electrical equipment noise

- -of the following potential noise sources which are factors and how can they be controlled?
  - .boilers, burners and associated equipment

- .refrigeration machinery
  - -use vibration mounts for moving parts
  - -separate foundation from building structure
  - -use flexible pipe couplings
- .cooling tower including fan noise and water flow
- .circulating pumps
  - -should be well-balanced
  - -isolate vibration by mounts or foundations
  - -use flexible pipe connections
- .air-conditioning units
  - -separate vibration from structure
  - -check manufacturer's sound rating
  - -use canvas collar connections to ducts
- .air-handling units remote from central station equipment
  - -use resilient supports to structure
  - -use braced, stiffened or damped sheet metal walls
  - -use canvas collar connection to ducts
  - -check manufacturer's rating on fan and air noise
- .ductwork
  - -relate air velocity to noise restriction
  - -use round, sound-absorbent ducts for high-velocity systems
  - -streamline turns and size changes to avoid turbulence or use turning vanes
  - -select grilles with consideration for noise
  - -possibly provide beneficial masking background sound
  - -check for cross-talk through short lengths of duct between rooms
  - -use crossbreaks or other stiffening of flat sheet metal duct walls
  - -provide acoustical duct lining to reduce noise in ductwork as required by intensity, kind and location of sources and the requirements of the rooms
- .steam radiation
  - -one-pipe air-vent systems should be avoided
  - -design for low velocity of steam flow
  - -avoid pockets in piping which will trap condensate and block steam flow
  - -provide for expansion/scraping against adjacent surfaces or stressing of parts
- .hot water heating systems
  - -design for low water velocity
  - -eliminate air pockets to avoid noise in flow through piping
  - -provide adequate arrangements for expansion without scraping or cracking noises
- .room units
  - -select fan coil units for quiet operation
  - -locate room exhaust fans for quiet operation
  - -check sound ratings from manufacturers

- .plumbing
  - -isolate vibration from water pumps and sewage ejectors
  - -check potential water hammer
  - -provide quiet action faucets and other water control devices and sanitary fixtures
  - -insulate noise of flow through drainage piping
- .electrical work
  - -use quiet-acting switches and sound-rated fluorescent lamp ballasts
  - -locate and enclose transformers
- .maintenance
  - -excessive noise is a common result of careless maintenance practices
  - -provide detailed and specific maintenance instructions and a schedule for various pieces of apparatus

Occupancy noise

- -which of these occupancy noises are factors and how can they be handled?
  - .movement of people through corridors and other circulation areas
    - -by sound deadening floor covering
    - -by sound absorption in walls and ceilings
    - -by sound dividers and cut-offs
  - .speech as it affects adjacent spaces such as offices, conference rooms, classrooms and auditoriums or large-group classrooms
  - .speech from public address systems and audio-visual aids
  - .music as unwanted sound in adjacent spaces such as:
    - -individual practice rooms
    - -small practice rooms
    - -large-group practice rooms
    - -performing spaces such as auditoriums
  - .other occupancy noise sources include:
    - -seating, furniture and equipment in general
    - -lockers
    - -swimming pools
    - -gymnasiums
    - -locker rooms
    - -kitchens and cafeterias
    - -office and office equipment
    - -shops
    - -home economics rooms

The quality of ambient noise

- -identify existence of specific intermittent or information-carrying background sounds which require covering by "acoustical perfume", such as class sounds in an adjacent room or intermittent sound from special activities
- -determine any specific problems of dominant frequencies
- -identify noise generating spaces such as kitchens and locker rooms where the problem within these spaces is primarily that of a general noise reduction
- -define methods of reduction such as use of absorbing material in the room
- -identify spaces where more than normal care must be used to avoid interfering noise, such as in rooms for speech therapy, music practice rooms and musical theory rooms
- -consider need for variation in acoustical environment which is similar to variations in visual space, qualities of color, size and shape
    - .corridors might deliberately admit noise from outside sources as a relief in going from one quiet room to another
    - .certain spaces should be noisy such as a gym during a basketball game
    - .certain spaces should always be quiet such as a study room or library

Determining ambient sound levels

- -considering above factors develop a schedule of rooms and appropriate NC curves for spaces where frequency control is important
- -considering the above factors schedule additional rooms where frequency control is not a significant factor

CONSIDERATIONS FOR LARGE INSTRUCTIONAL SPACES

Sound transmission factors of the room

- -to what degree can pronounced resonant frequencies be predicted?
- -do parallel hard surfaces exist in locations likely to pick up and cause multiple reflections of impulse sounds?
- -do reflecting surfaces exist in locations to produce echoes?
- -are reflecting surfaces located in appropriate positions to pick up wanted sound and distribute it with adequate and uniform intensity?

CHECKLIST

- are there provisions to reinforce sound if necessary?
- is there deliberate provision for diffusion by convex or irregular wall and ceiling surfaces?
- is the floor sloped or stepped to provide adequate elevation of successive rows of seats into the stream of sound?
- is the basic shape of the room such as to cause problems of sound distribution?
  - .too long and narrow
  - .ceiling too low
- does the plan conform approximately to the normal fanshaped spread of sound from a source or are areas located too far to one side or to the rear of the source?
- are there recessed or shielded areas which may not receive sufficient sound?
- is the room volume appropriate to the primary purpose of the space?
- do the conditions vary substantially with the number of students in the room?
- are the frequency-absorption characteristics appropriate as measured by variation in reverberation time?
- is air absorption a factor?

Special consideration for musical qualities

- have the following points been considered where musical performance is important?
  - .acoustical intimacy or presence
  - .liveness
  - .warmth
  - .definition or clarity
  - .brilliance

Special considerations for speech

- check maximum Percentage Syllable Articulation for the volume concerned; is it adequate for the degree of understanding required and the variety of the speakers?
- is the room sufficiently live to respond to sound especially for children hesitant to recite and with poor speaking voices?